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GEOLOGICAL MAGAZINE

with which is incorporated

THE GEOLOGIST

Founded in 1864 by the late Dr. Henry Woodward, F.R.S.

Edited by

R. H. RASTALL and O. M. B. BULMAN

assisted by

Professor W. S. Boulton
Professor W. G. Fearnsides
Sir Thomas H. Holland
Professor O. T. Jones
Professor C. E. Tilley
Professor W. W. Watts
Henry Woods
Sir A. Smith Woodward

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GEOLOGICAL MAGAZINE

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The Geology of British Oilfields

2. The Geology of the Oilfields and some Prospective Oil Areas in Canada

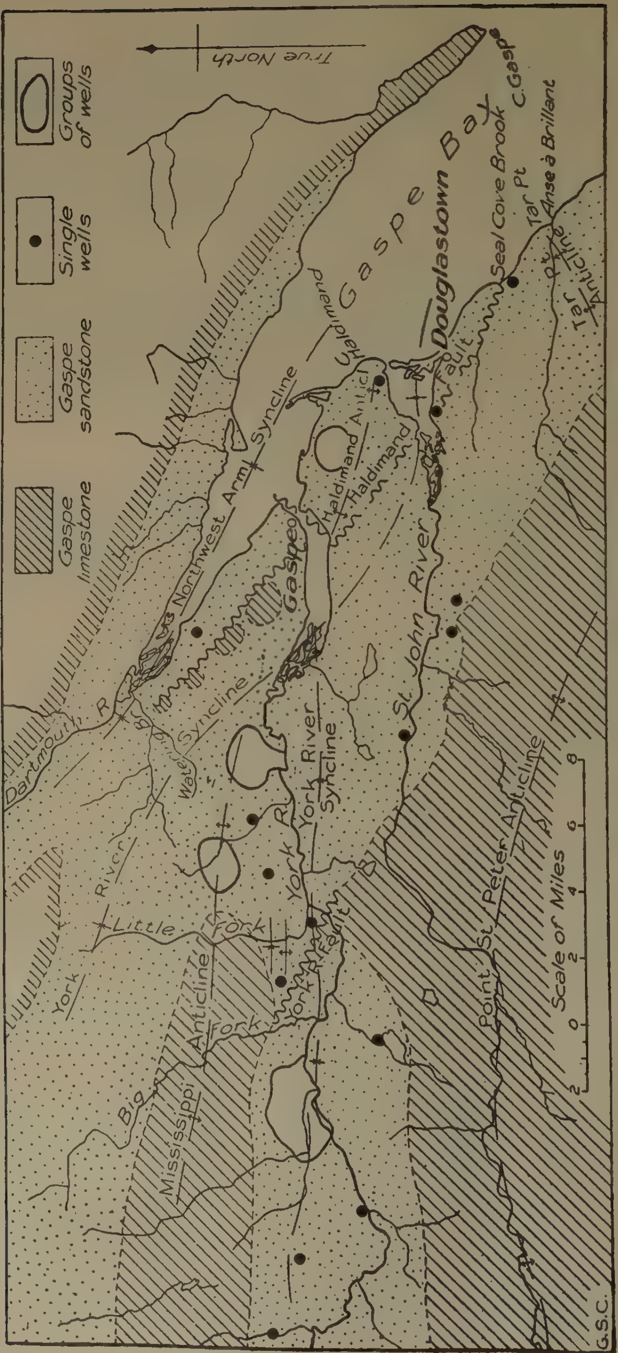
By G. S. HUME, Geological Survey of Canada

INTRODUCTION

PETROLEUM is produced in Canada in New Brunswick, Ontario, North-West Territories, and in Alberta. Recently a new oilfield has been opened up on the Alberta-Saskatchewan boundary at Lloydminster. Prospecting at the present time is also being undertaken in Gaspe Peninsula of Quebec and in the Peace River Block of British Columbia.

GASPE PENINSULA

The Gaspe Peninsula (Hume, 1932) is a part of the Appalachian system of mountains which in the United States trend in a north-east direction, but in Gaspe turn to the east and then to the south-east where the mountain folds are truncated by a very rugged coastline (Alcock, 1926). The north coastline follows the structural trend and is a smooth curve without harbours. The interior of Gaspe is a plateau rising to an elevation of 4,200 feet above the sea and extending for fifty miles along the middle of the peninsula. The oil-bearing region is east and south-east of this plateau principally in the drainage basins of York and St. John Rivers and embracing an area forty or more miles east and west by ten miles north and south (Text-fig. 1). The oil prospects are related mostly to Devonian rocks, but Silurian strata underlying these may be of some importance. The geological history of Gaspe peninsula is rather complex, but the main features are known. The rocks of early Palaeozoic age were laid down in successive seas that at one time or another covered the whole area. Both the northern and southern margins of the area were uplifted so that the central part became a basin which in Devonian time was occupied at different stages by fresh and marine waters in which a great



TEXT-FIG. 1.—Gaspe Oil Field, Quebec. (From map by W. A. Parks.)

thickness of sediments was deposited. Subsequent movements raised the whole peninsula and folded it into a series of synclines and anticlines. Igneous activity occurred both during the deposition of the Devonian rocks and later during the period of folding. The lowest beds of the Lower Devonian are generally known as the Gaspe Limestone Series. These consist of limestones and shales and in the upper York river area it is thought (Jones, 1935) they may well be over 4,000 feet thick, although at the coast, thirty miles to the east, the thickness is considered to be only half this amount. In the upper York river area the Gaspe limestones are overlain by the York Lake series, possibly also of Lower Devonian age, consisting of sandstones with associated limestones and in a few places some thin conglomerate beds. The York Lake series varies in thickness from 2,000 feet in the south-east to possibly 4,000 feet in more westerly areas. Toward the east the upper members appear to have been eroded prior to the deposition of the Middle Devonian Gaspe sandstones. At the head of York River near York Lake a 20 ft. sill of porphyry occurs in the York Lake formation. The Gaspe sandstones are best known from the coastal region where exposures occur on Dartmouth, York, St. John, and Malbaie Rivers. They consist of a series of cross-bedded sandstones and conglomerates mostly of freshwater deposition, but partly marine, and are believed to be of Middle Devonian age. Logan assigned a thickness of more than 7,000 feet to them. In the basins of York and St. John Rivers the sandstones are commonly bituminous.

Seepages were first described from Gaspe peninsula in 1846, following a visit there by Sir William Logan of the Geological Survey of Canada in 1844. This was the first statement in regard to the occurrence of petroleum in anticlines, but a clear statement of the anticlinal theory was not made until 1861 when T. Sterry Hunt set forth his ideas in an address in Montreal on 1st March of that year. In Gaspe, seepages occur in many localities, in some places issuing from the limestones but more generally from the overlying sandstones. Sir William Logan in the *Geology of Canada*, 1863, described a number of these seepages particularly on Dartmouth, York, and Malbaie Rivers.

The main period of folding affecting the possible oil bearing Devonian strata occurred toward the close of the Middle Devonian. The period of Appalachian folding which affected Eastern United States in the Permian did not extend on any large scale at least into Gaspe, since rocks of either late Devonian or Carboniferous ages in the vicinity of Chaleur Bay to the south of Gaspe are little disturbed. During the Middle Devonian deformation, however, the older Devonian beds were strongly folded and many anticlines and synclines have been outlined ; dips of 20 to 25 degrees are common although much steeper dips are known and overturned beds may be present.

The first drilling was undertaken in Gaspe in 1860, but a much more persistent effort was made in 1889 when the Petroleum Oil Trust organized in England began operations. In the next few years more than fifty wells were drilled, some of which were more than 3,000 feet deep and many of them were 2,000 or more feet in depth. Some of these wells penetrated the Gaspe sandstones into the underlying limestones. Many of the holes were dry or yielded only salt water and small volumes of gas. A few, however, yielded oil in sufficient quantity to encourage the building of a short pipe-line and the erection of two refining stills each of 150 barrels capacity. This optimism was not justified by the amount of oil obtained and operations ceased in 1902. During recent years, however, the Quebec Department of Mines has done considerable geological work in this area and last autumn a well was undertaken by the Imperial Oil Company. The well is located on York River about fifteen miles above its mouth. It is now standing at a depth of 1,136 feet and will be completed this summer.[1]

It is agreed that structures favourable for the accumulation of oil and gas are present in petroliferous beds, but as far as known the presence of reservoir beds is still somewhat in doubt. In many places the limestones are highly siliceous and it has been suggested (Parks, 1929), that this silica may have been derived from the leaching of volcanic ashes during the time of Devonian sedimentation.

NEW BRUNSWICK

All gas and oil production in New Brunswick is confined to one area south of Moncton, the geology of which is shown in Text-fig. 2. The oldest rocks in the area, probably Precambrian in age, consist of a metamorphic and igneous group that underlies an upland, plateau-like area known as Caledonia Mountain, where the maximum elevation is about 1,200 feet above sea level. Overlying these rocks is a group of Carboniferous strata underlying the flanks of the upland and also the country to the east and north, which slopes away from the upland surface. These younger rocks are divided into the Horton and the Windsor series, the latter consisting of three formations, the

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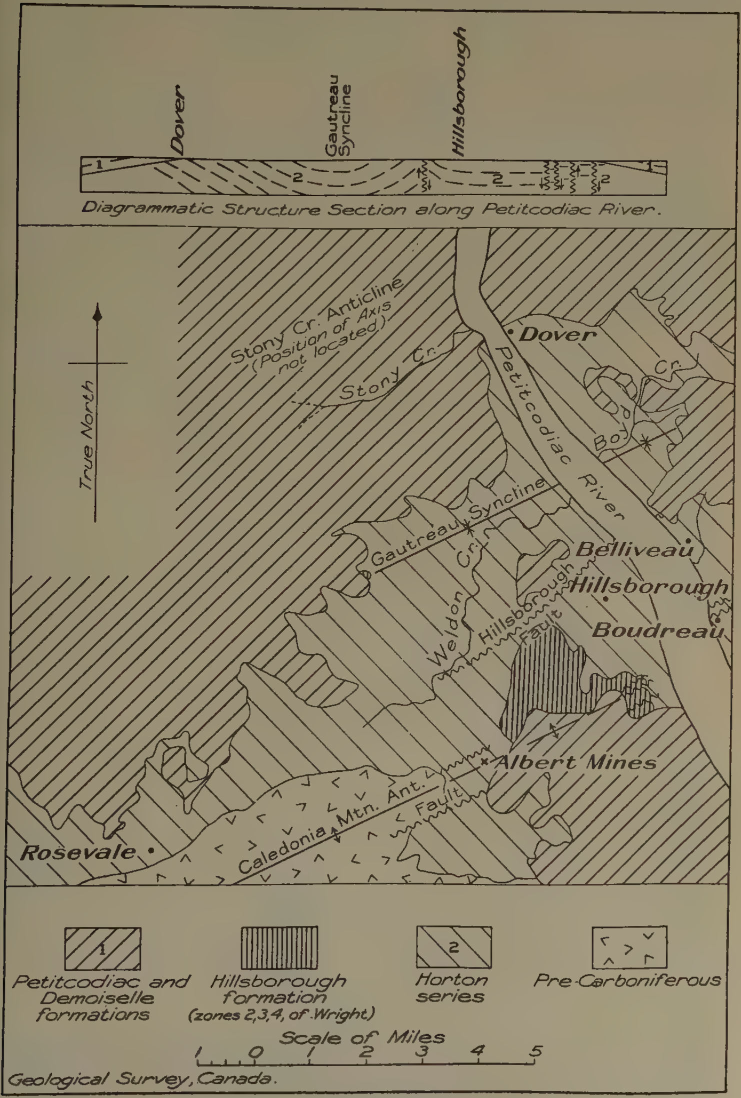
[1] This article was prepared in April and May, 1940—ED.

Hillsborough, Demoiselle, and Petitcodiac. The Petitcodiac is Pennsylvanian in age and the others are Mississippian.

The beds that yield gas and oil are 5,000 to 6,000 feet thick and belong to the Albert formation of the Horton series. They consist mainly of grey shales although at intervals grey sandstone



TEXT-FIG. 2.—Geology of the Stony Creek Gas and Oil Field, New Brunswick.

beds are intercalated with the shales. Thick beds of bituminous shale occur especially in the lower part of the formation and grey limestone beds are locally present. The Albert formation is thought (Bell, 1927) to be lacustrine in origin, deposited in a basin which is known to be at least fifty miles long and twenty to thirty miles wide north of Caledonia Mountain. Its full extent, however, may not be known since part of it is buried under younger deposits. On the north edge of Caledonia Mountain the Albert shales rest on the Precambrian rocks, but to the east older beds are present. In the Gautreau syncline both east and west of Petitcodiac River thick beds of salt are present. Wells on the east side of Petitcodiac River have penetrated 500 to 900 feet of the salt formation, whereas one well on the west side of the river penetrated about 1,500 feet of salt-bearing beds. On the north flank of the Gautreau syncline there is a group of red and grey shales with ash beds. The upper part of these beds contains a conglomerate with fragments of the ash beds from the lower zones indicating a considerable break in sedimentation. This conglomerate is identical lithologically with a basal conglomerate of the Hillsborough formation as exposed near Albert Mines and this part of the formation belongs to the Horton series whereas the remainder of the formation, consisting in part of limestones and in part of gypsum-anhydrite beds, is placed in the Windsor series. Unconformably overlying the Hillsborough formation there are beds of conglomerate, sandstone, and shale of the Demoiselle formation which overlap all older formations. The structure of these beds corresponds with that of the overlying Petitcodiac formation of Pennsylvanian age and this consists of a thick deposit of grey to buff quartz-pebble conglomerates, sandstones, and red shales. These beds dip gently northward and to the south they overlap the Demoiselle formation on to the north flank of Caledonia Mountain.

Owing to the disconformable relationship between the Demoiselle formation and older strata and to the overlap of the overlying Petitcodiac formation the structure of the Stony Creek oil and gas field is largely concealed. The main field has been developed on the south flank of the anticlinal fold believed to be present in the Albert shales.

ONTARIO*

The south-western peninsula of Ontario bounded by Lakes Huron, Erie, and Ontario, has a record of sustained petroleum production for eighty years. The area is underlain by Palaeozoic strata ranging in age from Ordovician to late Devonian. In general the beds dip at low angles of about 20 to 30 feet to the mile to the south and south-west, and since this dip exceeds the slope of the surface in the same direction the beds become progressively deeper buried under younger strata to the south and south-west. The Niagara escarpment beginning in Canada at Niagara River and responsible for Niagara Falls, extends north-west across Ontario to the north end of Bruce Peninsula between Lake Huron and Georgian Bay. It also occurs farther north-west on Manitoulin Island off the north shore of Lake Huron. West and south of the Niagara escarpment outcrops are relatively scarce and the bed rock is concealed by a thick deposit of unconsolidated clays, sands, and gravels. It is in this area, however, that all the oil and gas fields occur and as shown by wells the thickness of Palaeozoic nowhere exceeds 4,500 feet.

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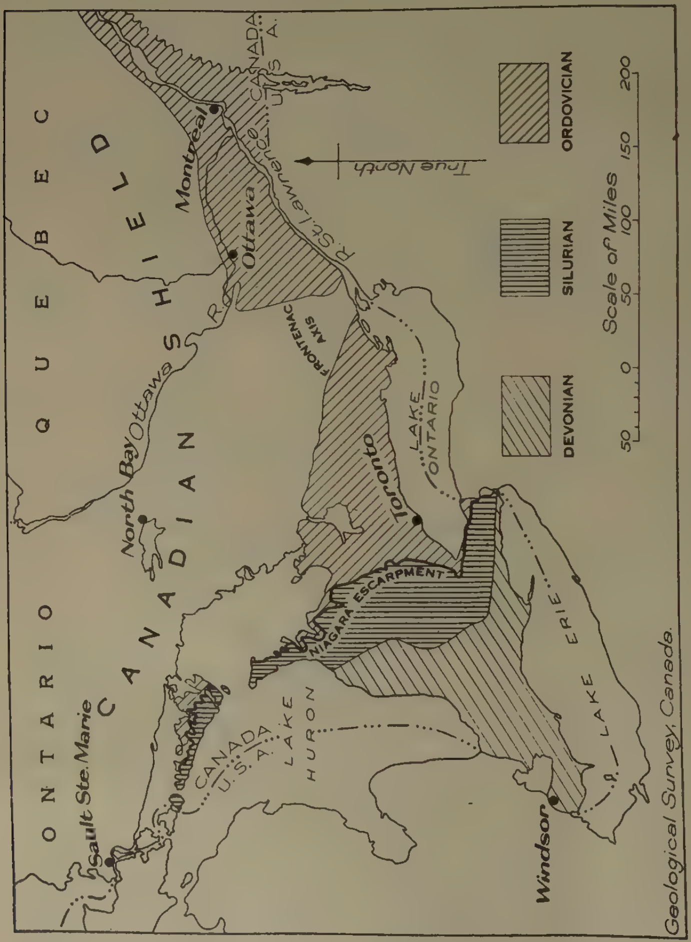
* Information in part from unpublished manuscript: Evans, C. S., and Stewart, J. S., Geological Survey of Canada.

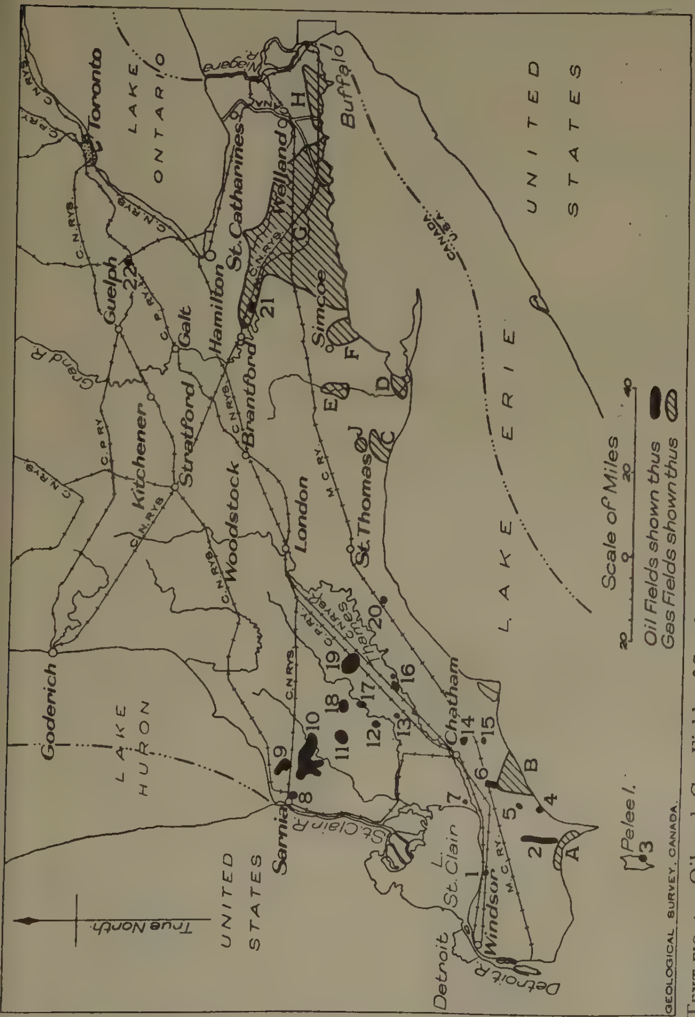
The Precambrian rocks under the Palaeozoic of South-Western Ontario are mainly gneisses, schists, and granitic types, but in various places crystalline rocks, presumably similar to the Grenville series, occur. The strata overlying the Precambrian are mainly arkose or sandstone beds varying considerably in thickness and character as would be expected from deposition on an uneven erosional surface. The age is believed to be Ordovician and there are no Cambrian beds west of the Frontenac axis (Text-fig. 3). These basal arkose beds have yielded oil in one or two wells, but very little production is to be expected from them ; in various places they contain a saline water with a high percentage of calcium and sodium chlorides. Above the basal arkose is the so-called Trenton group of the Lower Ordovician which varies in thickness from 500 to nearly 1,000 feet with the thicker sections in Lambton and Kent counties in the south-west part of the Peninsula. Only one commercial oilfield has so far been found in the Trenton group. This is the Dover field near Lake St. Clair. It is probable that fracturing and faulting produced the necessary porosity in this field and hence the lack of production elsewhere (except for small flows of gas) may be ascribed to lack of porous horizons. In Ohio and Indiana, where the Trenton group has given large production of oil, the porosity has been ascribed to an erosional interval between the Trenton and overlying shales. It may be that such an erosional break is largely absent in South-Western Ontario, although it has been recorded from exposures on Georgian Bay and Manitoulin Island (Sproule, 1936).

In the vicinity of Georgian Bay the Trenton group is overlain by 33 feet of bituminous shales and in 1859 at Collingwood on



TEXT-FIG. 3.—Geology of Southern Ontario.

Georgian Bay these shales were distilled for oil, but the project was later abandoned. These shales with other grey shales are what was formerly grouped under the name of Utica and these in turn are overlain by greenish grey shales. The whole assemblage is Cincinnatian in age. Only small amounts of gas have been found in these beds, but one occurrence at Caledon, north of Toronto, is interesting because of a content of eight-tenths of 1 per cent helium. Unfortunately only small volumes of gas were available after the drilling of several wells. The Queenston red shales are the youngest Ordovician beds in the Niagara area, and to the north-west the red shale is replaced by grey shale and dolomite. These beds are barren of oil and gas. Thus it may be said that as far as production of oil is concerned the Ordovician of south-western Ontario has yielded very little



Text-fig 4.—Oil and Gas Fields of Southern Ontario: Oil Fields 1, Belle River; 2, Leamington 3, Pelee Island; 4, Wheatley; 5, Romney; 6, Tilbury; 7, Dover West; 8, Sarnia; 9, Plympton; 10, Petrolia; 11, Oil Springs; 12, Dawn; 13, Thamesville; 14, Kipp; 15, Raleigh; 16, Bothwell; 17, Euphemia; 18, Brook; 19, Mosa; 20, Dutton; 21, Onondaga; 22, Milton. Gas Fields A, Leamington; B, Kent; C, Bayham and Malahide; D, Port Rowan; E, Middleton; F, Simcoe; G, Haldimand County; H, Welland J. Brownesville.

other than from the Dover field, but in future prospecting the Trenton group would seem to offer the most favourable opportunities for possible commercial yields.

The Silurian overlying the Ordovician shows quite wide variations in the stratigraphy (Williams, 1919), particularly in the lower part, and locally several members are productive of gas with some oil. For example, the basal member of the Silurian in the Niagara area is the Whirlpool sandstone 25 feet thick. This is a reservoir rock and has yielded gas in the Niagara area with oil in one small field near Brantford (Text-fig. 4). It does not extend far to the west of the Niagara area. In the overlying series of shales, sands, and dolomites, there are some red and grey sandstones of the Cabot Head-Grimsby group that have yielded gas over extensive areas. The total thickness of the whole of the Lower Silurian is probably not more than 200 feet. The Middle Silurian beds consist of limestones and dolomites and these form the crest of the Niagara escarpment. Their total thickness varies from 100 to 400 feet. The upper member—the Guelph dolomite—contains in its upper part the most important gas-producing horizon of South-Western Ontario, and has yielded large quantities of gas in fields in Kent, Lambton, Essex, and Oxford counties. It also has yielded oil in a number of fields, but the present yield is relatively small. The Upper Silurian beds in the south-western peninsula of Ontario belonging to the Cayugan group consist of fine-grained dolomites, grey shales, beds of gypsum or anhydrite, and in many places beds of salt. The salt beds vary widely up to 350 feet, and in one well near Sarnia 640 feet of salt was reported. This variation in the thickness of salt accounts for a wide variation in the thickness of this group of beds from 300 feet to more than 1,000 feet. The lower part of this formation yields gas and has also yielded some oil.

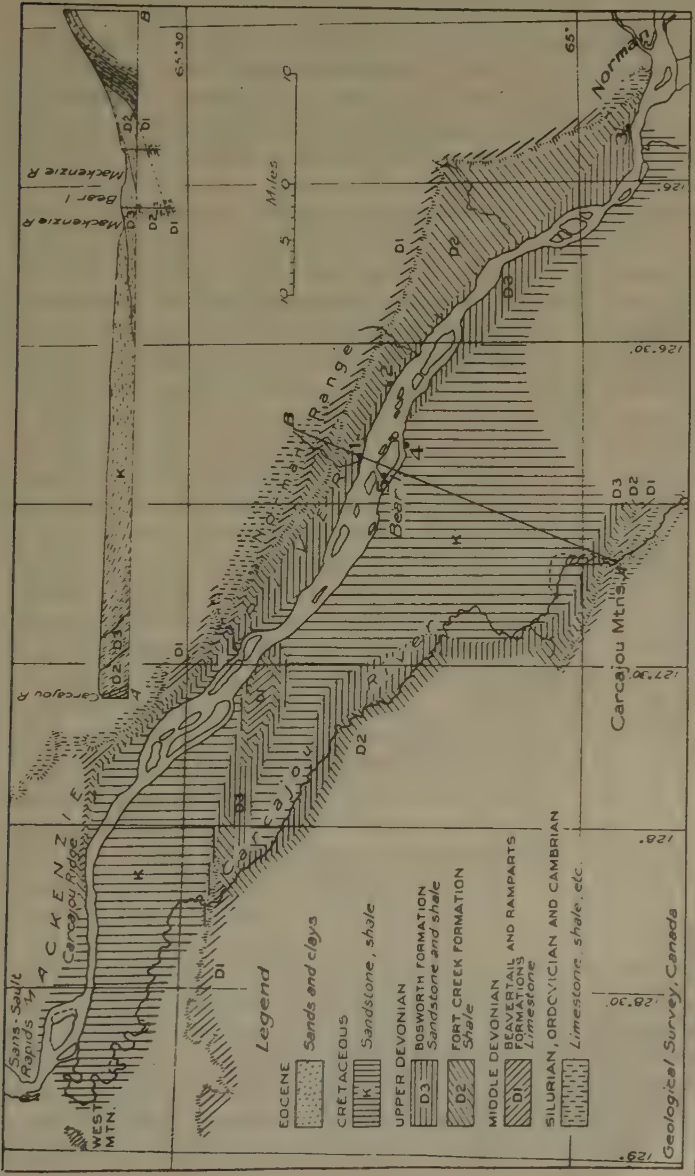
The Lower Devonian overlying the Silurian is known from wells to consist of limestones and dolomites with some thin sandstone members in certain localities. Outcrops, however, do occur in the vicinity of Detroit River and on islands in Lake Erie on the western edge of a broad syncline which contains younger strata. These Lower Devonian beds, so far as known, are unproductive of oil and gas. They are overlain by Middle Devonian limestones from 60 to 200 feet thick, which have been the most prolific source of oil in Ontario, and it is from these that the first wells in Ontario obtained oil at shallow depths up to 400 feet. The Middle Devonian limestones are overlain by further Middle Devonian shales and thin limestones, and in most areas these are the cover beds for the oilfields of Middle Devonian age. In the central part of the syncline, extending from Lake Erie through Kent and Lambton counties to Lake Huron, there are Upper Devonian shales which in part are black and bituminous and contain up to ten gallons of oil a ton. These are the youngest strata of the south-western peninsula of Ontario.

The structure of the south-western peninsula of Ontario is relatively simple. There is a gentle south-west dip of 20 to 30 feet to the mile to the south and south-west and in the vicinity of Kent and Lambton counties in the south-western part of the peninsula there is a broad shallow syncline. Regionally, however, the south-west dip of the beds continues into the Michigan Basin to the west where there are found strata younger than any that occur in Ontario. The Middle Devonian limestones of Ontario, which produce oil at a depth of less than 400 feet, are also productive of oil in the Michigan Basin at a depth of about 3,000 feet. The oilfields associated with Middle Devonian limestones in South-Western Ontario are all in anticlines of small closure in the synclinal structure extending through Lambton and Kent counties. In Enniskillen township in Lambton county seepages of oil were known to the Indians and earliest settlers, and development only awaited the use of the oil. This began in 1857 when Mr. W. H. Williams, of Hamilton, undertook the distillation of the tarry bitumen from a seepage at the present site of Oil Springs in order to fill a demand for illuminating oil. It was soon discovered that by drilling below the asphaltic residue of the seepage the material was more fluid so that in 1858 a well was drilled to a gravel bed filled with oil overlying the bed rock. The first well into the bed rock was drilled at Oil Springs in 1861 following the success of the Drake well in Pennsylvania. It reached the oil producing horizon at a depth of 160 feet. This led to great activity and many wells were drilled reaching the oil horizon at less than 400 feet in depth. Many of these wells flowed several hundreds of barrels a day, and several flowed a thousand to six thousand barrels, whereas the largest is said to have been the Black and Mathewson well which flowed seventy-five hundred barrels a day. As there was no means of controlling the flow of the wells much of this oil was wasted and flowed down Black Creek to Lake St. Clair. The success in the Oil Springs field led to the development of the Petrolia field a few miles distant. These two fields still continue to yield oil, and of a total production for Ontario of 206,196 barrels for 1939, these fields yielded over 80,000 barrels after almost eighty years of continuous operations. Oil Springs, the earliest field to be discovered, has yielded approximately 7,856,500 barrels of oil from an area of about 1⅓ square miles and still continues to yield at slightly more than 30,000 barrels a year without showing any decline in the last ten years.

NORTH-WEST TERRITORIES

In the Mackenzie River Basin in the North-West Territories there are two producing oil wells 50 miles north of Fort Norman at the junction of Great Bear and Mackenzie Rivers, or about 100 miles south of the Arctic circle. Production from these wells is only about 20,000 barrels a year, but owing to the fact that this oil is used for fuel and power in the mining of pitchblende on Great Bear Lake and gold on the north arm of Great Slave Lake the production is relatively important.

In the Mackenzie Basin and mountains of the Fort Norman area, strata consisting of Cambrian, Ordovician, Middle and Upper Devonian, Cretaceous, and Eocene are known to be present. Seepages of oil are very common in Upper Devonian beds and all production so far obtained comes from strata of this age. Cambrian and Ordovician beds are known to occur in the Carcajou mountains on the west side of the Mackenzie Basin, but their character and extent have not been studied in any detail. They consist mostly of red and green shales and sandstones ; the lower part is definitely known to be Cambrian, but the age of the upper or assumed Ordovician part is much more doubtful. However, Ordovician red beds with gypsum are present on Great Slave Lake and elsewhere in the Mackenzie Basin. The Silurian is somewhat better known. In the Mount Charles area on Great Bear River the lowest beds are gypsiferous shales, but the extent of these beds has not been determined. To the south in Franklin Mountains the lowest Silurian beds consist of 500 feet of calcareous shales with red interbeds grading upward into buff limestones. These strata are Lower Silurian in age (Williams, 1922). In the Franklin Mountains south of Great Bear River and west of Mackenzie River the Lower Silurian beds are overlain by 560 feet of Middle Silurian limestones and these in turn by 1,500 feet of Upper Silurian limestones. In the area north of Great Bear River the combined thickness of beds believed to be Middle and Upper Silurian in age is 1,400 to 1,500 feet. These consist of Middle Silurian well-bedded limestones overlain by about 400 to 500 feet of beds which so far as is known are devoid of fossils and in places contain thick gypsum beds. In other places these same beds are highly porous with vughs of considerable size. Where such conditions are present there is little or no stratification. These highly porous rocks under proper structural conditions are capable of



TEXT-FIG. 5.—Geology of Norman area, District of Mackenzie, North-West Territories: 1, Producing oilwells; 2–5, Non-producing oilwells. 1, Northwest Oil Co., No. 1 and No. 2; 2, Fort Norman Oil Co.; 3 Northwest Oil Co., Bluefish well; 4, Northwest Oil Co., "C" location; 5, Northwest Oil Co., "D" location (on Bear I.).

acting as excellent reservoir beds for oil and gas, and they are somewhat bituminous in certain localities.

North of the oil wells, which are 50 miles north of Fort Norman, the Silurian limestones are overlain by about 300 feet of dark shales, and these in turn by 650 to 700 feet of massive Middle Devonian limestones. Middle Devonian strata are widely known in Western Canada across the whole of the Prairie Provinces into the mountains and northward from the international boundary between the United States and Canada to the Arctic islands. The character and thickness of the beds changes considerably in such a large area, but over most of it the Middle Devonian consists of limestones and dolomites. On Great Slave Lake, Middle Devonian strata contain abundant oil seepages from a very porous dolomite, and two wells were drilled many years ago to test the prospects. The structure, however, at one of these wells at least, was not considered very favourable for oil accumulation within the Middle Devonian beds themselves since the dolomitic oil horizon with seepages outcropped at the well.

The Upper Devonian in the Fort Norman area consists of about 1,500 feet of dark shales of the Fort Creek formation overlain by 1,600 to 2,000 feet of the Bosworth formation of sandstones and shales. The Fort Creek shales are so highly bituminous in some places that they have been burnt to clinkers presumably by spontaneous ignition. Where such action has occurred the shales have been turned to a red colour and the shales in part have been melted into slag-like material. Vermilion Creek, near the wells at Fort Norman, gets its name from the colour of the burnt shale. In certain areas large lenses of sand occur in the Fort Creek shales, but at the wells which are only 150 feet apart and were drilled at the location of a large seepage, the oil actually comes from the shales themselves which at this place are undoubtedly fractured. The Bosworth formation overlying the Fort Creek shales contains a great many sand beds favourable for oil reservoirs. These alternate with greenish grey shales. The whole assemblage is marine and contains abundant fossils.

The Cretaceous is unconformable on the eroded top of the Devonian. There apparently was some regional movement in the time interval separating strata of these two ages and it is suggested the period of uplift could have been at the end of the Carboniferous or in early Mesozoic, when deformation took place in other parts of the Cordillera system. The Cretaceous consists of marine beds overlain by non-marine strata with coal. The marine shales offer excellent cover for the retention of oil in the Bosworth sands under favourable structural conditions. They are found in the vicinity of Fort Norman on the west side of Mackenzie River. The thickness of Cretaceous is unknown.

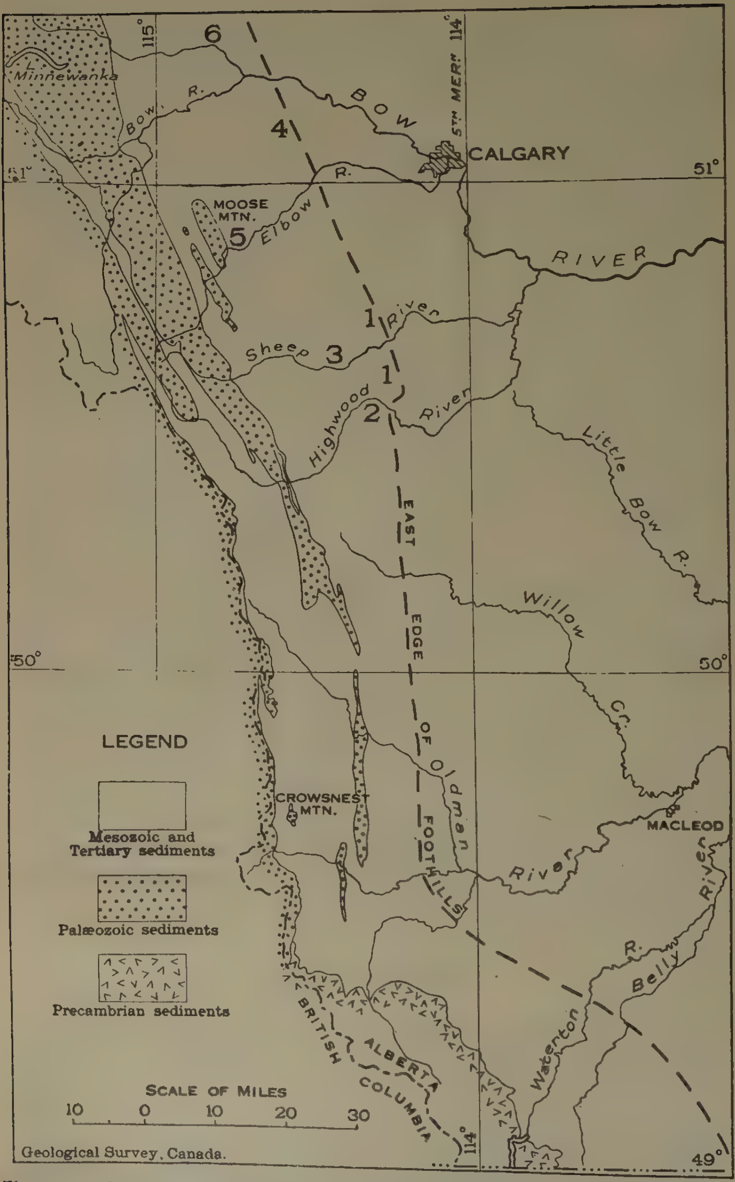
Eocene beds (Hume and Bell, 1921) unconformably overlie all older strata in the Mackenzie area and are undisturbed by the folding that occurs in these older beds. The Eocene contains the burning coal seams on Mackenzie River near Great Bear River. These were noted by Mackenzie in 1789 and still continue to burn.

The structure across the Mackenzie Basin is shown in Text-fig. 5. It will be noted the beds at the oil wells show no reversal in dip to give closure to the east. Folds that cross the Mackenzie Basin obliquely are known in various places, but owing to the fact that the soft beds are largely concealed by muskeg in the inter-stream areas and the massive Middle Devonian limestone more effectively resists erosion, only such folds as expose a core of Middle Devonian or older strata are known. It is to be expected, however, that other folds buried beneath Cretaceous beds are present though the location of these may be difficult to discover.

North-west Nos. 1 and 2 are the producing oil wells from depths of 1,000 to 1,100 feet. During 1939 another well was drilled 2,700 feet up river from No. 1 well. This well failed to secure oil in volume. It is planned to drill still another well in 1940 about 1,200 feet down river, i.e. north-west from No. 1 well. Nos. 1 and 2 wells are pumped throughout the year and a new refinery of a daily capacity of 840 barrels was erected at the well during the summer of 1939. It will operate only during the summer months. Aviation gasoline will be made and refined oil products will be supplied for mining operations in the North-West Territories.

FOOTHILLS OF ALBERTA

In 1939 Canada produced approximately 7,743,000 barrels of oil of which 7,456,000 barrels or 96 per cent came from Turner Valley (Text-fig. 6) in the foothills of Alberta, 35 miles south-west of Calgary. The foothills occupy a belt 12 to 20 miles wide in front of the Rocky Mountains extending from the International Boundary between the United States and Canada north-west for 800 miles to Liard River. North of this there is an offset eastward in the mountain ranges and, as already pointed out, the Mackenzie River area is a



TEXT-FIG. 6.—Foothills Area in South-Western Alberta: 1, Turner Valley Oil and Gas Field; 2, Highwood uplift; 3, Waite Valley; 4, Jumpingpound structure; 5, Moose Mountain Palaeozoic outlier; 6, Wildcat Hills.

basin between mountain ranges on both sides of this river. The geology of the foothills is best known in Southern Alberta and in other places where major rivers offer relatively easy means of access, but much of the northern area has not been studied. Major rivers like the Oldman, Bow, Peace, and Liard, cut across the foothills from west to east regardless of the north-west and south-east structurally trending ridges and hence they are part of an antecedent drainage system. The structure of the foothills is complex and the Mesozoic rocks of which they are mainly composed are highly faulted and folded with great overthrust blocks in the Palaeozoic resting on one another on their adjacent edges. Within the foothills there are also outlying masses of Palaeozoic limestones in elongated ridges. Most of these are faulted along their eastern edges, but one exception is Moose Mountain (Text-fig. 6), 30 miles west of Calgary, which is a fold. The type of structure in these Palaeozoic outliers is similar to the type of structure along the main front of the Rocky Mountains. The Rocky Mountains are composed mostly of fairly massive Palaeozoic rocks and because of their much greater resistance to erosion they stand at considerably higher elevations than the softer Mesozoic rocks of the foothills.

Stratigraphy

The Palaeozoic rocks in the foothills are known from a number of outliers and from drilling. The main source of information, however, is from the adjoining mountain front where Palaeozoic strata are overthrust on to Mesozoic rocks. In a number of places Devonian rocks are known to rest on Cambrian beds without any Ordovician or Silurian being present. Rocks of both these ages, however, do occur elsewhere in the Rocky Mountains. The Devonian consists almost wholly of limestones and dolomites, and in the southern foothills the thickness is 3,000 to 3,500 feet. Several wells have been drilled into the Devonian either in or on the flanks of Palaeozoic outliers such as at Moose Mountain, west of Calgary, and at Clearwater, 80 miles north-west of the same place. At Moose Mountain, one well is producing a small volume of oil from a depth of less than 1,500 feet in the Devonian. The well commenced drilling close to the top of limestones of this age in a canyon where the overlying Mississippian limestones and shales were largely eroded. The top of the Devonian is marked by a very dark bituminous shale, in places 20 feet thick ; it is known for 100 miles along the edge of the mountains, and is present under the Plains of Southern Alberta. It is an excellent horizon marker. In the Clearwater Palaeozoic outlier, previously mentioned, a well also commencing near the top of the Devonian encountered strong oil shows at 1,100 to 1,300 feet in depth. Apparently, however, the beds had a low degree of permeability, and a considerable amount of anhydrite was noted from well cuttings. Anhydrite and gypsum are known in the Devonian from Moose Mountain, but only as thin layers in the limestones or dolomites. On the plains of Southern Alberta a deep test drilled in the Bow Island gas-field encountered about 40 feet of anhydrite in the Devonian and other wells have penetrated anhydrite-bearing beds.

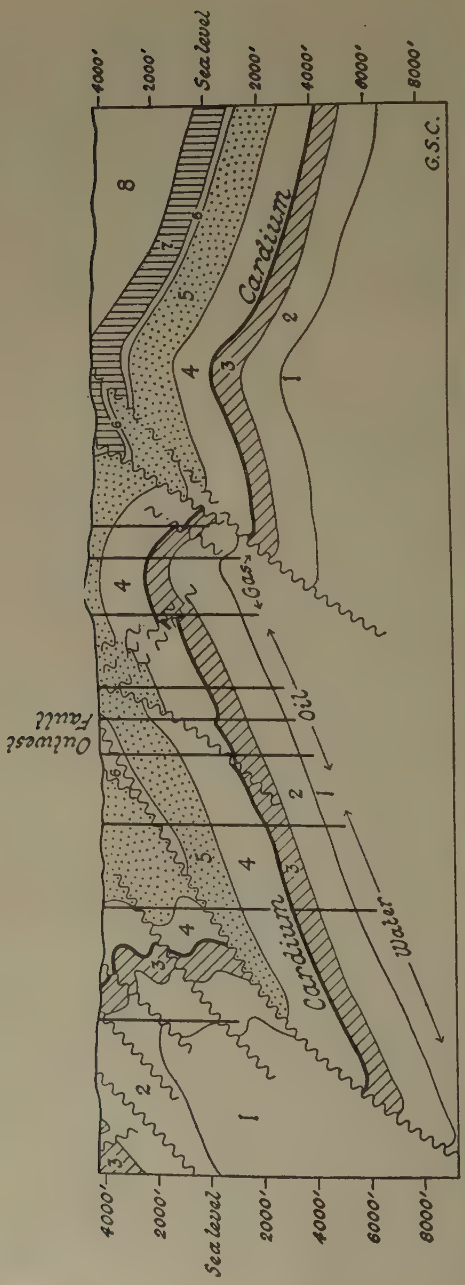
The Mississippian which overlies the Devonian is represented in the southern foothills of Alberta by 700 feet of limestones and limy shales overlain by 1,400 feet of massive and crystalline limestones and dolomites of the Rundle formation. It is in the upper 350 to 400 feet of the Rundle limestones that the main oil and gas zones of Turner Valley occur. The top of the Rundle where exposed in Moose Mountain west of Calgary is a chert conglomerate overlain by dark Jurassic shales. Triassic beds are present in the Banff area only 75 miles away, and are present in the western foothills in areas north of Bow River, but so far as known are not present in the eastern foothills in Southern Alberta. In Turner Valley the Jurassic beds are only about 200 feet thick, and these are in turn overlain by Cretaceous beds. The Lower Cretaceous of the southern foothills is entirely non-marine. In the Crowsnest Pass area of Southern Alberta the oldest Lower Cretaceous beds are sandstones and shales of the Kootenay formation. These strata contain the coal seams mined at Fernie, McGillivray Creek, Blairmore, and Bellevue. In Turner Valley the Kootenay is never over 100 feet thick, and in some wells it is not recognized at all. The formation thickens quite rapidly westward, and a few miles west of Turner Valley several hundred feet of beds are present. The Kootenay is overlain by further non-marine beds of the Blairmore formation. In Southern Alberta these beds do not contain any large coal seams, but in the Mountain Park and Cadomin areas west of Edmonton the main coal seams are in strata of this age. In Turner Valley one coal seam is present about 650 feet from the top of the formation that there is 1,050 to 1,200 feet thick. The base of the Blairmore in western foothills areas is marked by a massive conglomerate containing chert and quartzite pebbles. In Turner Valley this horizon is known as the Dalhousie conglomerate and sandstone and is relatively fine although easily recognized. The lower part of the Blairmore in Turner Valley contains about 150 feet of limy sandstones with shales immediately underlying a fairly coarse granular quartz sandstone known as the " Home sand " which yields oil and gas in some wells. The Home sand is probably quite local in its development. Above it the Blairmore consists of green shales, grey sandstones, and maroon shales at one or two horizons. Conglomerates occur locally particularly in one horizon which is called the McDougall-Segur sand, and is 200 to 400 feet from the top of the formation. These conglomerates differ from the conglomerate at the base of the Blairmore in that they contain pebbles of porphyry. Presumably these are derived from uplifted masses of igneous rocks to the west and are an evidence of the orogeny then taking place in the Western Cordilleran area. In the Crowsnest area of Southern Alberta the Crowsnest volcanics intervene between the Lower Cretaceous non-marine beds and the overlying marine Upper Cretaceous shales of Colorado age. On Ghost River and elsewhere north of Bow River the contact is in places marked by as much as a foot of bentonite, and everywhere the basal Upper Cretaceous shales contain a grit or sandstone that in a few areas is a conglomerate with pebbles and cobbles up to a few inches in diameter. This bed in Turner Valley is known as the " Grit ". It may be only a few inches to more than a foot thick, or it may be in two or more horizons separated by shales. On Highwood River west of the south end of Turner Valley beds belonging to this phase of sedimentation are as much as 20 feet thick and commonly are underlain by 10 to 20 feet of dark shales above typical Blairmore strata. The so-called " Grit " therefore belongs in the Upper Cretaceous.

The Upper Cretaceous in the southern foothills consists of 2,500 to 3,000 feet of marine shales known as the Alberta formation, overlain by non-marine beds that greatly increase in thickness northward. In southern foothill areas it is commonly possible to separate the Alberta formation into upper and lower parts since they are separated by a sandstone called the Cardium. In Turner Valley the Cardium sandstone is about 40 feet thick. About 150 feet above it is a pebble zone not more than 2 inches thick, consisting of fine black, green, and pink pebbles with polished surfaces usually about the size of rice grains, but occasionally somewhat larger. Another similar pebble zone occurs about 100 feet below the Cardium sandstone. To the west of Turner Valley these pebble zones become conglomerates on the top of sandstone horizons, so that the Cardium in these western areas really includes all beds between the upper and lower sandstone and conglomerate members. To the north of Bow River the amount of shale between the various sandstones decreases until the whole thickness becomes what is known in more northerly areas as the Bighorn sandstone. The persistence of the thin pebble beds without any sandstone is one of the remarkable features of the Alberta formation of Turner Valley, and where well samples are taken at regular intervals of 10 feet as now required the pebble zones are always observed. The Alberta formation is mostly Colorado in age, but the upper 300 feet or more of the upper part is Montana containing a large *Baculites* and other fossils. It is probable that the division between Alberta shales and the overlying non-marine beds of Belly River age is not always drawn at precisely the same horizon. On the west flank of Turner Valley there is a sandstone member 50 or more feet thick capped by a thin pebble bed and separated from non-marine beds by about 500 feet of marine shales. A few miles west this sandstone becomes very massive and in places quite conglomeratic and where exposures are not good it is impossible to separate it from the Belly River beds above. However, in Turner Valley and for at least 100 miles north along the eastern foothills there is a thin coal seam about 20 to 30 feet above the top of the highest marine Alberta shales. This horizon, although consisting of not more than 6 inches to 1 or 2 feet of coal and coaly shales, is always present and is most remarkable for its extent and persistence. In Turner Valley the Belly River formation consisting of alternating sandstones and shales is 1,700 feet thick. It is marked by a fairly thick coal seam at the top—the coal that is mined on the Plains of Southern Alberta at Lethbridge. In the eastern foothills of Southern Alberta the Belly River is overlain by marine Bearpaw shales. These thin and disappear westward and have not been recognized in the foothills north of Bow River. The overlying Edmonton formation is non-marine sandstones and shales about 1,100 feet thick east of Turner Valley, and these beds are in turn overlain by the Paskapoo formation of Tertiary age. Where the Bearpaw disappears north of Bow River it becomes increasingly difficult to separate the Belly River from the Edmonton since the coal horizon at the top of the Belly River cannot be identified. Also the Edmonton cannot be separated from the overlying Paskapoo even though in certain Plains areas of Southern Alberta the two are divided by an erosional disconformity with a conglomerate at the base of the Paskapoo formation. The problem of a division in this non-marine series north of Bow River is made more difficult by a great increase in thickness. The whole group of beds in the Nordegg coal basin, 120 miles north-west of Calgary, is known as the " Saunders group ", and is upwards of 14,000 feet thick. It is, however, divided into an upper and lower Saunders group separated by coal-bearing beds. In the vicinity of Bow River certain hills are capped by conglomerates that unconformably overlie all older beds. These are believed to be later Tertiary, although no fossils are known from them. They are the youngest beds known in the southern foothills.

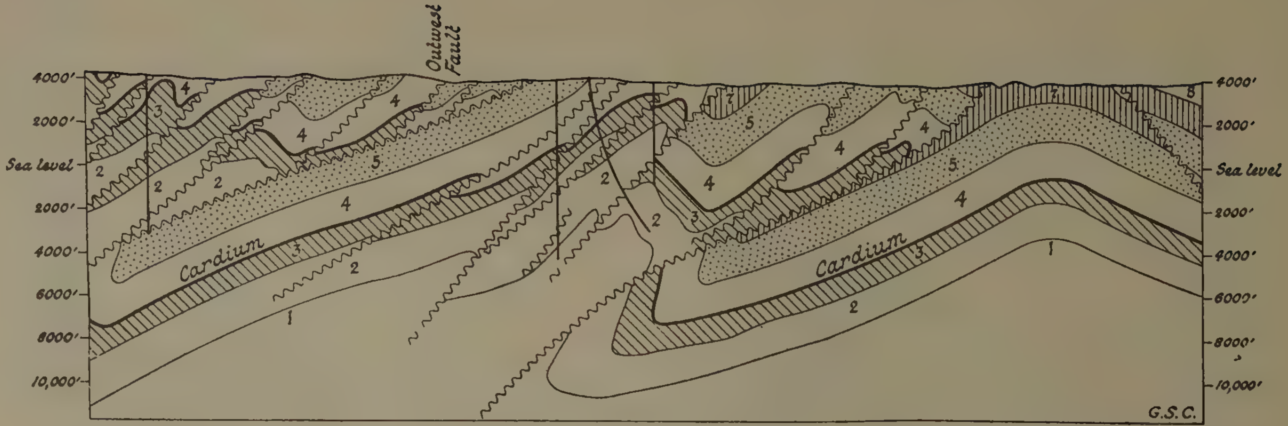
Structure

Great difficulty has been experienced in interpreting the structure of the foothills because of the fact that the softer Mesozoic beds and the underlying more resistant Palaeozoic limestones yielded differently under severe mountain-building forces. It thus happens that complicated structures in the softer beds may not be reflected in the underlying limestones. Since, however, the location of the uplifted limestone masses is of prime importance in the search for oilfields these must be sought by an interpretation of the regional structure of the overlying Mesozoic beds. In the study of foothills structure the drilling in Turner Valley has supplied details that could not otherwise have been obtained. In this field more than 200 wells have now been drilled to the Palaeozoic limestone over a length of about 18 miles so that the field is defined in an east, west, and south direction. It is probable that it may extend for some distance farther north. The Geological Survey has made extensive studies of Turner Valley and these are shown on two cross-sections herewith presented (Text-figs. 7 and 8). Also an attempt has been made to interpret other structures in the light of this information, and although success in the location of new oilfields has not yet attended these efforts it appears to the writer that the key to the structural situation in the Jumpingpound area west of Calgary has been given by a recently completed well there. A cross-section of the Jumpingpound area 20 miles north-west of the north end of Turner Valley is, therefore, included here (Text-fig. 9), showing the interpretation in reference to a possible uplift of limestone to the west of the wells that have been drilled.

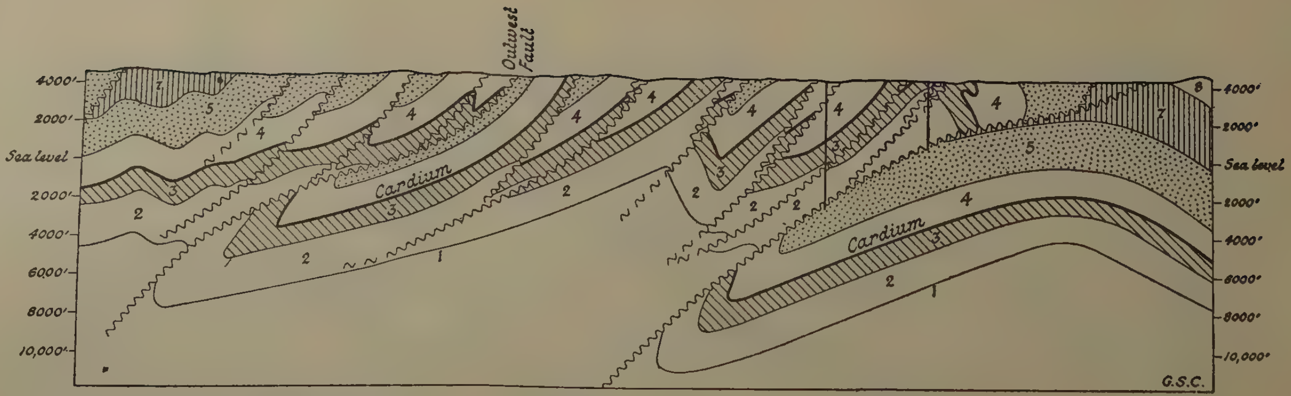
In general, Turner Valley is a fault block cut off by a major fault on both sides and with the Palaeozoic limestone showing a westward dip of 20 to 25 degrees in the south end of the field.



TEXT-FIG. 7.—Cross-section of Southern Turner Valley. 1, Palaeozoic; 2, Lower Cretaceous and Jurassic; 3, Lower Alberta formation; 4, Upper Alberta formation; 5, Belly River formation; 6, Bearpaw formation; 7, Edmonton formation; 8, Paskapoo formation.



TEXT-FIG. 8.—Cross-section of Northern Turner Valley. 1, Palaeozoic; 2, Lower Cretaceous and Jurassic; 3, Lower Alberta formation; 4, Upper Alberta formation; 5, Belly River formation; 7, Edmonton formation; 8, Paskapoo formation.



TEXT-FIG. 9.—Cross-section of Jumpingpound area. 1, Palaeozoic; 2, Lower Cretaceous and Jurassic; 3, Lower Alberta formation; 4, Upper Alberta formation; 5, Belly River formation; 7, Edmonton formation; 8, Paskapoo formation.

On the east edge the limestone is drag-folded above the fault and this is reflected by a well-marked anticlinal structure in the Belly River and Alberta formations on the surface. Drilling for gas with naphtha [1] has been done throughout the whole length of the field to the more uplifted parts of the limestone although some parts have been much more intensively drilled than others. On the west flank of the surface anticline, wells have reached the limestone at a sufficient distance down the dip to obtain oil whereas still deeper wells have penetrated the water below the oil. The dip of the limestone fault block has been shown to be uniform and in general faults present on the surface within the width of the main block do not cut the limestone. In the central part of Turner Valley the dip of the limestone may be as low as 15 degrees, but at the south end of what is known as the north proven area, the dip is much steeper for a limited area. It again flattens off northward. This relatively gentle dip on most of the Palaeozoic limestone is in marked contrast to the surface dips of the Mesozoic beds. Belly River strata on the east and west flanks of Turner Valley rarely dip less than 50 degrees and on Sheep River, which transversely intersects central Turner Valley, the dips are 65 to 70 degrees. On the surface the anticlinal structure is fairly symmetrical and for this reason no major fault on the east side was suspected until it was encountered by wells. Undoubtedly at depth on the east side above the major fault there are overturned beds, although on the east flank of Turner Valley overturned beds are absent or only present to a very slight degree in one area where vertical beds occur. The occurrence of gentle dips on the limestone and steep dips on surface beds is at least partly explained by rotation on faults which may have considerable displacement on the surface but die out at depth above the limestone. A fault in Southern Turner Valley, known as the Commoil fault, is a good illustration. In Commoil No. 1 well this fault gave a repetition of 1,290 feet of drilling, encountering the Belly River–Alberta shale contact first at a depth of 1,460 feet, reaching the fault at 1,970 feet, and encountering the same contact again at 2,750 feet. In wells to the west of this the fault was encountered at lower levels and showed less displacement, until finally in wells still farther west the fault had passed into a bedding-plane slip and could not be recognized. It can easily be seen how such a fault which started as a bedding-plane slip as an adjustment in the softer beds above the limestone would cause a large rotation where the magnitude of displacement was very considerable at the surface. This, then, is at least a partial explanation of the steep surface dips on the west flank where the structure is complicated by numerous surface faults. All faults are in general steeper than the beds cut by them so it is to be expected that most of the faults at the surface will be steep as is known to be the case in many outcrops. The Commoil fault was the first indication in the foothills that the inclination of some faults changes at depth because in a number of cases information derived from drilling indicated that the faults at the surface were fairly uniform with a dip of approximately 60 degrees. In Southern Turner Valley certain sandstones in the Alberta shales have been repeated once or even twice in several wells. This has been interpreted by the writer as the result of a zone of east-dipping faults, a back thrust resulting from the drag on the major overthrust. This interpretation has not been wholly accepted and other geologists have preferred to think of these faults as a series of west-dipping faults. East-dipping faults have been proved to occur in a number of other structures in the foothills and always the displacement is moderate. It seems, therefore, logical to expect similar faults in Turner Valley. At least one fault which cuts the Palaeozoic limestone of central Turner Valley is generally regarded as having an eastward inclination and others may be present. This fault is, however, somewhat different from the east-dipping faults in Southern Turner Valley concerning which differences of opinion exist.

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[1] Naphtha is the local name for a light gasoline which is carried as a vapour in the gas of the gas dome overlying the crude oil. The reduction of temperature at the surface caused by the sudden expansion of the gas on relief of pressure causes the vapour to condense.—Ed.

The west side of the Turner Valley fault-block is cut off by the Outwest fault from the Highwood uplift. In the Highwood uplift the limestone is within very moderate depths of the surface and is known to rise to an elevation of more than 2,000 feet above sea level whereas the highest known elevation in Turner Valley is in Royalite No. 14 well at 786 feet above sea level. In spite of this, only shows of oil with water were encountered in the Highwood uplift whereas the water line in Turner Valley is at an elevation of more than 4,100 feet below sea level. The difference in the water level in the two blocks adjoining one another is, therefore, known to be more than 6,000 feet and may be 6,500 feet or more. From available information it thus seems that the Highwood block is effectively sealed off from the Turner Valley fault block by the Outwest fault, but that the water in the lower part of the Turner Valley fault block may be in open connection around the plunging south end of Turner Valley with the water in the Alberta syncline to the east, since the east side major thrust fault dies out southwards. Within the productive zones of the Palaeozoic limestone of Turner Valley the closure is, as already indicated, about 4,900 feet, which is phenomenal.

Turner Valley is now considered to be a structural ridge of limestone thrust-faulted on its eastern edge and in no way is it different from some outliers of Palaeozoic limestone of the foothills except that it is deeply covered by Mesozoic strata. In the northern end as now developed there is a shifting to the west due to the fact that the fault on the east side is believed to bifurcate and one part cuts across the east flank of Turner Valley thus throwing the edge of the limestone block farther west than was formerly expected. North of this, however, the normal north-west trend is resumed and although the buried ridge of limestone is assumed to plunge downwards across the valley of Fish Creek where Edmonton strata occur on the surface, it is thought the continuation of the same ridge rises in the Jumpingpound area west of the wells so far drilled. This interpretation, if true, will be of the greatest importance in further prospecting for oil, as is illustrated by the cross-section through the Jumpingpound area, 20 miles north-west of the north end of Turner Valley.

The information (Hume, 1940), from the Jumpingpound area is considered equally important to that from Turner Valley in the interpretation of foothills structure. Turner Valley on its east edge is a drag-fold in which the limestone is involved in the fold, whereas Jumpingpound is a similar type of structure in which the drag-fold involves only younger strata. Both structures are anticlinal at the surface and in both cases the fault cutting off the east side is not obvious from surface mapping since apparently it splits upwards into a series of faults each of which has a very small displacement at the surface. The two wells shown on the cross-section through the Jumpingpound structure (Text-fig. 9) both encountered the fault in the Kootenay-Fernie beds and passed back into Belly River strata. Thus as far as the beds above the fault are concerned, the fault was closely parallel to the bedding for the distance between the two wells, namely 1 mile. It is obvious that such a fault must have a tremendous displacement at depth in spite of not being readily recognized at the surface and at some place to the west of the more westerly well the fault must cut the Palaeozoic limestone. At the place where this occurs the limestone will be uplifted to the west and it is believed that this uplift coincides with the continuation of the Turner Valley limestone ridge from its known location in North Turner Valley, 20 miles to the south-east. The occurrence of this major fault in the Kootenay-Fernie beds may be connected in part with the coal in the Kootenay or it may be due to the fact that the Fernie forms a less competent member between the more competent Lower Cretaceous sandstones and shales above and the massive Palaeozoic limestones below. It is very significant that in addition to the wells in the Jumpingpound area, a number of other wells in the foothills have encountered major faults in the Kootenay and Fernie beds. Among these are Elbow Oils No. 1, Cottonbelt No. 1, and National No. 3 wells. These wells are widely separated and all on different structures. Any interpretation of structure must therefore take into account that the Kootenay and Fernie is the favourable locus for faulting and as far as is possible with present information the cross-sections here submitted have been drawn with this in view.

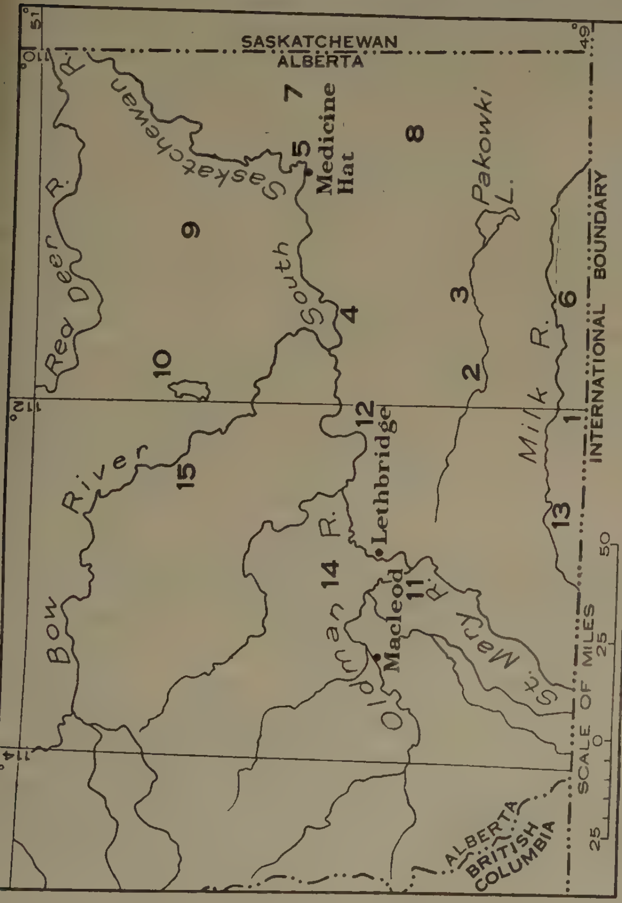
Production in Turner Valley

At the present time (April, 1940) there are 102 crude oil wells in Turner Valley producing from the Palaeozoic limestone from depths of 6,500 to slightly more than 8,500 feet. Drilling for crude oil began in June, 1936, following the completion of Turner Valley Royalties well in the south end of the field. There are ninety-two wells in the south end of the field in a length of 6 miles. Between the north end of the south-proven area and the south end of the north-proven area there are a few wells in a distance of 8 miles in structurally favourable territory. Certain wells drilled in this area were dry and others only gave a small yield. One well just completed, however, has had an initial flow before acidization at the rate of more than 1,500 barrels a day and further wells are drilling. In the north-proven area with a length of nearly 3 miles there are eight producing wells among which are some of the finest in the field. The north limit of the field is not known and the structure continues for at least 6 more miles beyond the most northerly well. The length of the field now being developed is thus 17 miles with a probable further extension northward. Production is restricted by the needs of the Prairie markets which amounts roughly to an average of 20,000 barrels a day for the year. At the end of 1939 two wells had produced more than 500,000 barrels each, three more than 400,000, nine more than 300,000, eleven more than 200,000, and thirty-four more than 100,000 barrels each. When it is considered that all these wells have been drilled since June, 1936, and that some have been in operation only a short time supplying a restricted market the record is good. The oil has a gravity of 40 or more degrees A.P.I. and contains 48 to 49 per cent gasoline on straight run distillation. The record drilling time (Taylor, 1940) up to the present is 110 days for a depth of 7,415 feet. Acidization is used to increase the flow of oil from the limestone.

PLAINS OF WESTERN CANADA

Several minor oilfields occur on the Plains of Alberta and one field is on the Alberta-Saskatchewan boundary at Lloydminster. In general the attitude of the strata throughout the Plains is very gentle and except in Southern Alberta where there are a few igneous dykes connected with the intrusive Sweet Grass Hills a few miles south of the International Boundary in Montana, there are no igneous rocks cutting the Palaeozoic or younger rocks of the Plains. The Sweet Grass Arch is a broad fold which along the International Boundary in Southern Alberta plunges northward. There was some uplift in this area at the end of the Carboniferous, when it is believed that the plunge of the structure was southward. As a result of this uplift and subsequent erosion, the Palaeozoic beds were bevelled off to the north so that although there are Pennsylvanian beds in Montana, none occur under the southern plains of Alberta. Also in Alberta the Mississippian strata that occur in the south were eroded to the north and at McMurray on Athabaska River, 270 miles north of the International Boundary, Cretaceous rocks rest on the eroded top of the Devonian. The Mississippian beds which contain the productive oil zones of Turner Valley are thus absent in Northern Alberta and their extent under the Plains is very imperfectly known. In a deep well drilled in Southern Alberta below 1,100 feet of Mississippian strata there were 895 feet of Devonian limestones with anhydrite. Below the Devonian, the strata consist of limestones, shales, and dolomites with considerable anhydrite. Cores taken contained fossil fragments sufficient to show the lower part of 507 feet of beds drilled were Cambrian in age. It is therefore assumed that the whole thickness is Cambrian and if so this would indicate Ordovician and Silurian beds are entirely absent. Both Ordovician and Silurian strata occur in Manitoba where the Ordovician overlaps on to the south-western edge of the Precambrian shield and Silurian strata are believed to underlie the Devonian resting on Precambrian east of McMurray on Athabaska River. In wells drilled through the Palaeozoic to the Precambrian at McMurray, salt beds occur below fossiliferous Devonian limestones. In one well 199 feet of salt was encountered between depths of 694 and 893 feet and the age is ascribed to Middle Silurian (Allan, 1937), although the beds contain no fossils. The distribution and character of the Ordovician and Silurian beds under the Plains can only be determined from deep wells and few of these have been drilled to sufficient depths to encounter rocks of these ages even though they may occur over large areas. The Devonian, however, is known to be widespread. In Manitoba, no Lower Devonian occurs but Middle and Upper Devonian limestones and dolomites outcrop between the edge of a Cretaceous escarpment and the Silurian and Ordovician beds lying along the edge of the Precambrian shield. In the McMurray area only Upper Devonian beds occur (Warren, 1933), but in the eastern Rocky Mountains at Lake Minnewanka, near Banff, both Middle and Upper Devonian limestones are present. The Devonian has yielded a small production of oil in one well in the Moose Mountain limestone outlier in the foothills west of Calgary. Also, since it is productive of oil in Ontario in Middle Devonian and in the North-West Territories north of Fort Norman in the Upper Devonian, it is the centre of considerable interest in the search for oil under the Plains of Western Canada. Recently a well drilled near Steveville on the Red Deer River, 100 miles east of Calgary, encountered a flow of 65 million cubic feet of gas at a depth of 5,258 feet or 1,638 feet below the top of the Devonian black shale which forms the division between the Devonian and the overlying Mississippian. A small amount of oil occurred with this gas and this has given rise to the hope the Steveville structure may also contain oil. The structure is very broad with gentle dips and a number of wells have shown large gas flows in horizons above the Devonian.

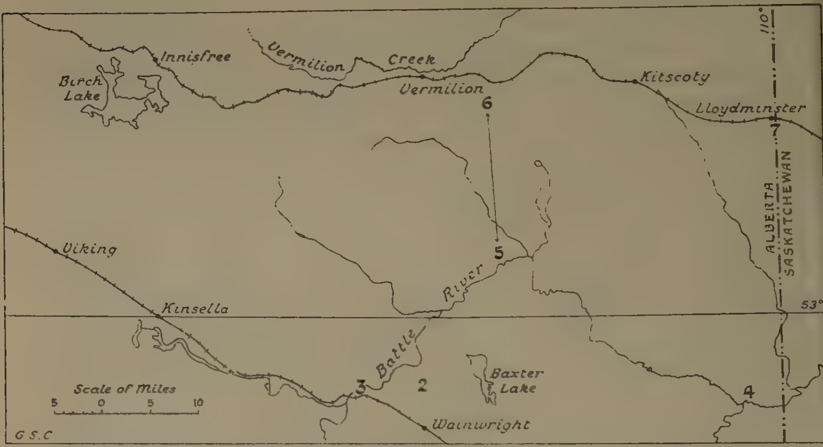
The Mississippian beds overlying the Devonian, as already mentioned, are bevelled off to the north. In Southern Alberta they offer prospects of oil and in a few places oil has been found in them. In Southern Alberta they are overlain by Jurassic shales, but these thin out and disappear to the north and east and are not present in the Wainwright area of East Central Alberta. Where the Jurassic shales are exposed on the sides of the intrusive buttes in the Sweet Grass Hills of Montana they are very bituminous (Sanderson, 1931). The thickness in Southern Alberta is less than 300 feet and only about half this amount over the Sweet Grass Arch which, as already indicated, was partly uplifted before Jurassic deposition. In the Skiff area (Text-fig. 10) of Southern Alberta some oil occurred in a sand in these Jurassic shales, but there is no present production. In Southern Alberta non-marine Lower Cretaceous sandstones



TEXT-FIG. 10.—Oil and Gas Fields of Southern Alberta: 1, Red Coulée area; 2, Skiff (Devenish) area; 3, Foremost gas field; 4, Bow Island gas field; 5, Medicine Hat gas field; 6, Milk River area; 7, Many Island Lake area; 8, Cypress Hills area; 9, Suffield area; 10, Brooks area; 11, Blood Indian Reserve—Spring Coulée area; 12, Taber—Barnwell—Chin Coulée area; 13, Twin River area; 14, Keho Lake area; 15, Eyremore area.

and shales overlie the Jurassic shales, but to the north where these thin out the Lower Cretaceous beds rest directly on Palaeozoic limestones. Sands in the lower part of the Lower Cretaceous produce oil in the Red Coulee-Border field on the International Boundary south-east of Lethbridge, and offer promise of production elsewhere. It is assumed the oil in them comes from the underlying Jurassic. In Southern Alberta the

Lower Cretaceous, probably about the equivalent of the Blairmore of the foothills, is entirely non-marine. In Northern Alberta at McMurray on the Athabaska River the Lower Cretaceous consists of an alternation of non-marine with marine beds. The lowest member, the McMurray formation, is a delta deposit and this contains the bituminous sands which are noted for their extent and thickness with a bitumen content up to 20 per cent. Above the McMurray deltaic deposit are the marine Clearwater shales, 275 feet thick. This is overlain by the Grand Rapids formation in part non-marine with coal seams and in part marine. The Grand Rapids formation is in turn overlain by the marine Pelican shales 90 feet thick. The seas in which these marine shales were deposited must have had their shorelines north of the totally non-marine deposits of the same age in Southern Alberta and it is now believed (Hume and Hage, 1940), that these shorelines crossed north-west and south-east through the Wainwright, Vermilion, Ribstone, Lloydminster areas (Text-fig. 11), where oil is now being produced from several small fields. The oil in these areas, therefore, may be directly related to the character of Lower Cretaceous sedimentation. All known structures in which the oil has been concentrated are relatively gentle, with dips of 20 to 50 feet to a mile or less. It is recognized that although production from the few small



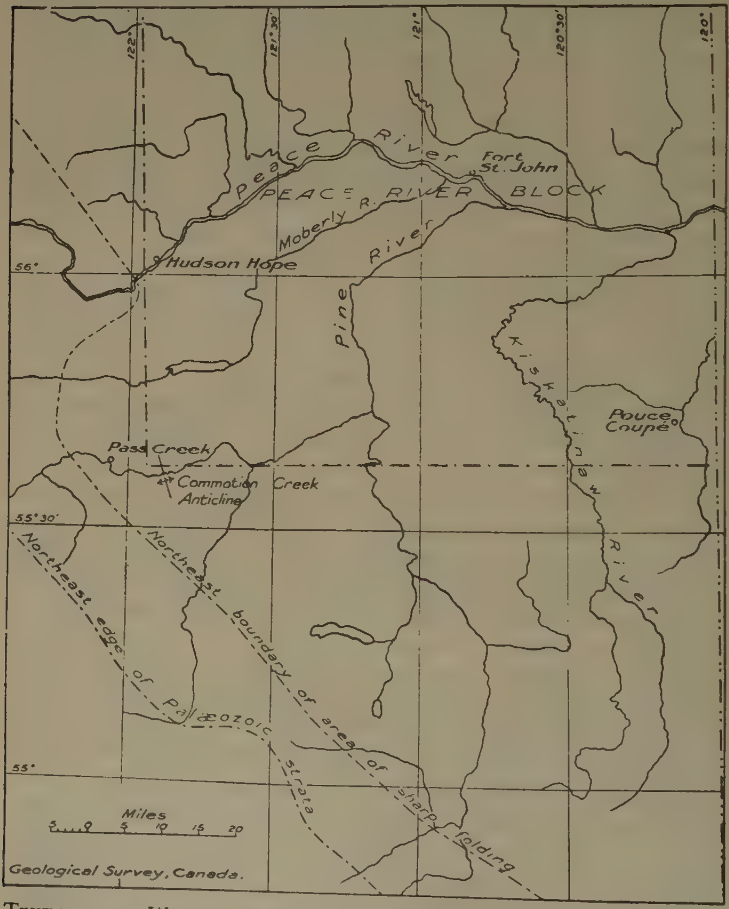
TEXT-FIG. 11.—Oil and Gasfields of East Central Alberta. 1, Viking field; 2, Wainwright field; 3, Fabyan field; 4, Ribstone field; 5–6, Battleview anticline; 7, Lloydminster field.

fields so far discovered in Eastern Central Alberta and Western Saskatchewan is at present small the prospects for new developments are excellent, extending from at least as far south as Wainwright, 270 miles north to the outcrop of the bituminous sands at McMurray.

The Upper Cretaceous of the Southern Plains began with the deposition of marine shales about 1,700 feet thick, but in the Peace River area of Northern Alberta the Dunvegan sandstone more than 500 feet thick is the basal formation of this age. The equivalent of the Dunvegan sandstone in more southerly parts of the Plains is not known, but in certain areas as at Foremost, Bow Island, and elsewhere in Southern Alberta (Text-fig. 10), and at Viking (Text-fig. 11) in Central Alberta, there are sands 150–350 feet above the base of the Upper Cretaceous shales that carry large volumes of gas. The Dunvegan sandstone (McLearn and Hume, 1927), is evidently a marginal delta or alluvial plain built out into an early Upper Cretaceous sea and may have extended to the Athabaska area where the Pelican sandstone may be its eastward extension. In the upper part of the Upper Cretaceous, extensive non-marine beds were deposited in Western Alberta ; but to the east the seas remained and in Manitoba the Upper Cretaceous deposits consist of a basal sandstone overlain by 1,000 to 1,100 feet of marine shales with thin limestone beds.

The Tertiary of the foothills, as already indicated, is entirely non-marine. This is true also of the Plains where in Southern Saskatchewan non-marine beds range in age from Lance to Palaeocene. Higher Tertiary beds are believed to occur in Turtle Mountain, Southern Manitoba, and Miocene beds (Sternberg, 1930) have been reported from the Wood Mountain area, Southern Saskatchewan.

In the Cypress Hills area of Southern Alberta and Saskatchewan conglomerates, sandstones, silts, and marls constitute the Cypress Hills formation of Lower Oligocene age. Similar conglomerates, sands, and marls occur in the Hand Hills, north-east of Drumheller on the Red Deer River. The Swan Hills in Northern Alberta south of Lesser Slave Lake are also capped by gravels that may be the same age as the Cypress Hills formation, although no proof of this is at present available. Reference has already been made to conglomerates capping the hills in the Bow River area of the foothills west of Calgary. In the Cypress Hills the Tertiary beds are more than 100 feet thick and although the pebbles are mostly small they vary to boulders with a diameter of 10 to 12 inches. The top of Cypress Hills is at an elevation of 4,800 feet and over 100 square miles of the upper part above 4,400 feet (Johnston and Wickenden, 1931) no glacial deposits occur, indicating that the continental glaciers did not override this area. The boulders and pebbles of the Cypress Hills conglomerates are presumed to have come from the west and since the Cypress Hills have not been uplifted locally it has always been a matter of speculation how high the mountains to the west must have been in order to give the necessary gradient for the transportation of these boulders for at least 200 miles. The Cypress Hills rise 1,600 feet above the level of the



TEXT-FIG 12.—Western Peace River area, British Columbia, showing Commotion Creek anticline.

surrounding plains to the west and the area intervening between Cypress Hills and the mountains gradually rises to the foothills at an elevation of 4,000 to 5,000 feet. It is obvious, therefore, that the amount of erosion in post-Oligocene time has been enormous, as is shown also by the evidence of isolated mountains such as Crowsnest in Alberta and Chief Mountain in Northern Montana, now separated by several miles from the overthrust mountain fronts with which they were formerly connected.

PEACE RIVER BLOCK, B.C.

This is part of the foothills extending north-west from Alberta and crossing Peace River in British Columbia (Text-fig. 12). The stratigraphy and structure of this area has recently received considerable attention from the Provincial Government of British Columbia, who propose to drill a well in 1940 on Commotion Creek, a tributary of Pine River, which in turn is a tributary of Peace River from the south. The strata exposed on the crest of the Commotion Creek anticline belong to the Dunvegan sandstone of Upper Cretaceous age, overlain by Upper Cretaceous shales and underlain by Lower Cretaceous beds of the St. John shale and Bullhead Mountain formations. The top of the Bullhead Mountain formation (of about the age of the Blairmore of Southern Alberta foothills areas) is exposed on the crest of the anticline in the valley of Pine River and the proposed well will commence drilling at about this horizon. The thickness of the Bullhead Mountain formation is not definitely known at this particular locality, but may be as much as 4,000 feet, all non-marine. Neither is the thickness of the underlying Jurassic and Triassic beds known. The Jurassic is not likely to be more than a few hundred feet thick, but the Triassic is known to thicken rapidly to the west and toward the western edge of the foothills there is approximately 3,000 feet of limestones and fine-grained sandstones. Undoubtedly at the well site the thickness will be considerably less than in the more westerly areas. The objective of the well will be to test the top of the Palaeozoic limestone.

The Commotion Creek anticline has some very interesting structural features not entirely understood. The Dunvegan sandstone on the west flank has a maximum dip of 11 degrees, and there is a closure on it of at least 1,500 feet before it starts to rise again from the bottom of a rather wide syncline. The east flank, however, is much steeper, which is an indication of the thrust from the west and might suggest the possibility of a drag-fold above a thrust-fault on the east side were it not for the fact that the Dunvegan sandstone is broken across a valley and obviously faulted either by a thrust-fault from the east or a normal fault with the downthrow to the west. There are various reasons why it does not seem probable that this is a normal fault and hence until further evidence becomes available the fault is tentatively regarded as having an east-dipping fault plane. The question of whether it cuts off a west-dipping fault underlying the structure will be determined by drilling and on this feature the prospects of the structure for oil and gas may largely depend. The depth of any well to the Palaeozoic limestone cannot be precisely predicted at the present time, but it would appear probable that a minimum depth is 7,000 to 7,500 feet.

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The Age of Certain Permian Fish-bearing Strata

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THE Permian fish-fauna of England has been studied by the present writer since 1932. In 1933 Dr. H. Aldinger, then working in Professor E. A. Stensiö's laboratory in Stockholm, informed me of the constitution of a fish-fauna from East Greenland which he was studying. The resemblances to the Marl Slate fishes were remarkable, and I found it extremely difficult, and in some cases impossible, to separate certain forms found in the two areas.

The English Marl Slate fishes also occur in the German Kupferschiefer, and these strata are generally regarded as Upper Permian. The East Greenland fishes come from the Posidonomyaschiefer, which were, in 1933, regarded as of "Permo-Carboniferous" age. The stratigraphical relations of the Posidonomyaschiefer are somewhat complex, but may be summarized as follows (see the papers by Frebold, Nielsen, 1935, Aldinger, 1935). They usually succeed the "Kalkdolomit", which rests with unconformity on crystalline rocks and has only yielded few and obscure fossils. The Kalkdolomit is regarded by Frebold as of the same age as the Schwagerinenstufe (or possibly the upper Uralian) of Russia. The Posidonomyaschiefer includes few fossils besides the fishes; most of these are apparently of little stratigraphical value and have not been described. The plants will be mentioned later. These strata pass up, sometimes by sharp passage, sometimes by intercalation, into limestones with typical late Palaeozoic brachiopods. These were at first called Brachiopodenkalk; Frebold (1932*b*, esp. 23–30) separated an upper part, called the Martiniengestein, and the remaining limestones are sometimes termed Productuskalk. It is generally agreed that the Posidonomyaschiefer, Productuskalk, and Martiniengestein are inconstant in their development, and show some degree of lateral passage (cf. Frebold, 1932*b*, fig. 4; 1932*c*, fig. 9). Thus in the region around Godthaab Gulf described by Nielsen (1935) the Posidonomyaschiefer is overlain by *Martinia*-limestone which includes only a thin band of *Productus*-limestone. These strata are therefore unlikely to differ much in age. Characteristic fishes of the Posidonomyaschiefer are found also in the Brachiopodenkalk.

Higher Permian strata are not known *in situ* in East Greenland. Frebold (1932*c*) has described a series of red and reddish-yellow calcareous sandstones which overlie the Brachiopodenkalk in

Wollaston Foreland. These strata have a fauna of few brachiopods (e.g. *Linoproductus*, cf. *konincki*, *Juresania juresanensis*, and *Spirifer cameratus*) and several molluscs (*Schizodus*, *Bellerophon*, etc.). Frebold considers them to be lateral equivalents of the Martiniengestein.

The Eotriassic conglomerates at several localities in East Greenland include boulders of limestones with Zechstein fossils, which have been studied by Frebold (1931*a*, 1931*c*, 1933). According to Frebold, the boulders include faunas representative of several stages of the German Zechstein ; six " Geröllgruppen ", each marked by distinctive petrographical and palaeontological characters, have been recognized. Groups I and II are referred to Upper and upper Middle Zechstein, V to lower Middle, III and IV to the Lower Zechstein. Group VI comprises boulders of Brachiopodenkalk. These light-coloured limestones, though occurring only as boulders, have been called the Cape Stosch formation. There is no indication of any strata between the Brachiopodenkalk and the Lower Zechstein, and it is a matter of inference that the " Cape Stosch formation " is younger than the Brachiopodenkalk instead of a lateral equivalent.

Frebold at first correlated the whole of the Brachiopodenkalk and the Posidonomyaschiefer with the " Upper Carboniferous " Schwagerinenstufe (now regarded as Sakmarian, lowest Permian) of Russia, on the basis of the brachiopod faunas. Later (1932*b*) he described two ammonoids from the Martiniengestein—*Medlicottia malmquisti* Fr., considered to be most closely related to early species of that genus, and *Godthaabites kullingi* Fr., regarded as structurally intermediate between the Cisco (late Pennsylvanian) *Shumardites* and the early Permian *Perrinites*. Frebold thus extended the upward limit of the Martiniengestein into the Artinskian ; the typical brachiopod of this limestone is compared with *Martinia triquetra*, recorded from the Artinskian of the Urals.

This determination of the age of the East Greenland fishes was the subject of correspondence betwen Aldinger and myself, and the manuscript of a thesis, embodying the results of my examination of the Marl Slate fishes, was lent to Aldinger, who quoted it largely and reproduced several figures in his monograph on the Greenland bony fishes (1937). He also attempted (1935) to correlate the Posidonomyaschiefer and Brachiopodenkalk on the one hand with the Marl-Slate and Kupferschiefer (i.e. the base of the Zechstein), and on the other with the Artinsk-Leonard part of the marine Permian series. He considered that the ammonoids show close resemblances to early Permian forms, particularly of " Mittleres oder Oberes Artinsk oder Unteres Leonard " age.

Meanwhile Frebold had showed that fossils from the Brachiopodenkalk of Nathorstfjord, previously identified by him as *Productus*, cf. *cancriniformis*, are identical with *P. cancrini germanicus*, the typical form of the German Zechstein conglomerate, immediately below the Kupferschiefer. This form he regards as quite distinct from the *P. cancrini rossicus* of the Russian Kazanian. As a result of comparison of Kazanian and Zechstein faunas, Frebold concludes (1933, p. 52) that the base of the German Zechstein is older than the Kazanian, and may even be as old as the " Ufastufe " of Russia. (See below, p. 42.)

The apparent disparity in age of the fish-bearing strata in Greenland and Europe was reduced by these manipulations, but it is probable that few were convinced of the suggested much earlier age of the Kupferschiefer and Marl Slate, in view both of the considerable resemblance between Kazanian and Zechstein faunas, and of the great development of the Rothliegendes. The invertebrates of the Brachiopodenkalk are considered to indicate an Artinskian and Sakmarian (*Schwagerina*) age, while the fishes of the underlying Posidonomyaschiefer are closely related to faunas usually accepted as of Middle or Upper Permian age, as shown below.

The Greenland fish-fauna consists of Elasmobranchs and Actinopterygians. The former were described by Nielsen (1932). They include Bradyodonts such as *Agassizodus*, *Fadenia*, ? *Edestus*, ? *Copodus* ; teeth of *Cladodus* ; teeth of *Janassa* ; and (in the Martiniengestein) the peculiar fin-spine *Arctacanthus uncinatus* and teeth doubtfully referred to *Campodus*. Immediately after Nielsen's account of these fishes was published, C. C. Branson described (1933, 1934) a remarkably similar fauna from the Pustula member of the Middle Phosphoria formation of Wyoming. Species of *Arctacanthus*, *Janassa*, *Agassizodus*, *Cladodus*, and ? *Edestus* are found in both. The Phosphoria formation is usually regarded as of approximately the same age as the Word formation of Texas, and thus younger than the Leonard-Artinsk.[1] It may be mentioned that a fish closely resembling *Fadenia*, from the English Marl Slate, is being studied by the writer.

The Actinopterygians were described by Aldinger (1937).

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[1] Branson (1933, 1934) considered the lower part of the Phosphoria to be Pennsylvanian. New evidence is mentioned below. Branson also notes the general resemblance between the brachiopod-fauna of the Pustula member of the middle Phosphoria and that of the Greenland Brachiopodenkalk (1934).

They show close resemblance to the Marl Slate-Kupferschiefer forms: *Palaeoniscus freieslebeni* Ag. occurs in both, *Pygopterus nielseni* Ald. is very little different from *P. sedgwicki* Ag., *Acropholis stensiöi* Ald. is a close relative of *Acrolepis murchisoni* Ag., and is even slightly " advanced " in certain structural details. *Plegmolepis* occurs doubtfully in the Marl Slate, and is found in the Kazanian of Russia. *Boreosomus* and *Elonichthys punctatus* Ald. are restricted to Greenland, and the European forms *Reticulolepis* Westoll (in Aldinger, 1937), *Globulodus*, *Dorypterus*, and *Acentrophorus* are unknown in Greenland. These differences mostly concern rare forms; the rest of the fauna is quite certainly closely similar.

It may be argued that such vertebrate remains are not of very great value in age-determination. This may be true of most Elasmobranch remains, especially if different species of the same " genus " of tooth or spine are concerned. But the Actinopterygians are mostly nearly complete, and offer a very large number of variable characters, such as details of skull-structure, ornament of bones and scales, arrangement of fins, etc., and closely similar or identical species are unlikely to differ very significantly in age. On the basis of the fishes alone, therefore, the Posidonomyaschiefer would be correlated with strata of Middle Permian (Phosphoria) or Marl Slate-Kupferschiefer (Late Permian ?) age. In this connection the work of Halle (1931) on plant-remains from the Posidonomyaschiefer is of interest. These remains were fragmentary and indeterminate, but Halle notes resemblances to conifers and indicates that they may perhaps be of Permian or even Lower Triassic age. (The latter is not possible on stratigraphical grounds.)

Recent work on the late Palaeozoic marine faunas has indicated the remarkable value of ammonoids and fusulinids as stratigraphical indices, and the correlation of strata on these grounds is now on a very much more certain basis, though there is great controversy concerning the exact level at which the Carboniferous-Permian division should be made. Miller and Furnish, in a work just published (1940) have provided important evidence bearing on the age of the Greenland Permian. They have examined a further collection of ammonoids from the *Martinia*-limestone of Clavering Island, and find it to consist entirely of the diagnostic late Permian ammonoid *Cyclolobus*. They remark: " The inner volutions of *Cyclolobus* resemble the small specimen on which Frebold based *Godthaabites*, and presumably the large specimens now available are conspecific with '*Godthaabites*' *kullingi*. *Cyclolobus* is characteristic of the late Permian, and therefore the ‘ Martiniengestein ’ of Clavering Island presumably represents this horizon. Forms similar to *Medlicottia malmquisti* occur all over the world in the Middle and Upper Permian ” (p. 25). They also refer to an ammonoid fauna from the lower portion of the Phosphoria formation of Idaho, and regard it somewhat tentatively as of Word or possibly slightly older (Leonard) age, and note that R. E. King has indicated a collective resemblance between the Phosphoria and Word brachiopods. The Word or later age of the middle Phosphoria is thus confirmed.

The exact stratigraphical status of the Upper Permian ammonoids may not yet be in a very satisfactory state in view of the general lack of connected series of rocks of this age bearing abundant cephalopods. The Greenland *Cyclolobus* must be of Upper Permian age, but it is possible that the species may be slightly older than those of the *Cyclolobus*-bearing beds of Djoulfa (Armenia), Chideru (Salt Range), or Ambilobé (Madagascar). But this new information throws open the whole question of the age of the Greenland fishes, and makes it easy to understand the close relation of the Greenland and N.W. European fish-faunas, and is also in accord with the resemblance of the sharks of Greenland and the middle Phosphoria horizon. At the same time it raises other problems in an acute form.

The most serious of these concerns the brachiopod-fauna of the Brachiopodenkalk. It is true that many of Frebold’s determinations are tentative, but the general appearance of the fauna seems well-established. The Productids described by Frebold (e.g. *P. porrectus*, *P. timanicus*, *P. inflatus*, *P. purdoni*, *P. weyprechti*, etc.), are mostly found in Russia, according to various records, throughout strata assigned to the *Cora* (Uralian), *Schwagerina* (Sakmarian), and Artinsk horizons. The Athyrids, with *Dielasma elongatum* and *Rhynchopora nitikini*, are said to range in Russia from the *Cora* (Uralian) to the Kazanian horizons. Many of the species concerned are thus long-range forms, but Frebold considers that they could only occur together in the *Schwagerina* (Sakmarian) or Artinsk horizons. Any proper analysis of this problem would involve the age-relations of a number of formations in Northern Russia and various Arctic islands, and there is still much confusion in this field. On this matter I have no means of forming any but the most tentative opinions, but certain considerations suggest that the difficulties are not insuperable.

Some comment on the nature and fauna of the Russian Permian developments seems to be necessary. The lateral facies-equivalents of certain groups of strata are still very much debated; thus quite recently Gorsky (1937) has observed that difficulties arise when the limits of the largely arenaceous Artinskian of the type-area are traced into limestone-deposits, and Tikchvinskaya (1937) has stated that the "Ufimian" series (Ufa-stufe) comprises lateral equivalents of strata ranging from the Upper Kungurian to the Tartarian inclusive.

The extremely long range of many of these late Palaeozoic brachiopods may indicate that they belong to very slowly-evolving, stable lineages, confined to well-marked facies. In any area, therefore, a change of conditions of sedimentation may bring about a great faunal change which is not stratigraphically significant. In the Russian and Arctic regions it appears that no great change in facies, so far as it affected the faunas, took place more than temporarily or in a few areas from the late Carboniferous into the Artinskian; but no later series of unchanged type has been described. It is not impossible that faunas of "Artinskian" type persisted in some areas after the close of the Artinskian of the type-region. It is interesting that several of the species used in the study of late Palaeozoic stratigraphy in the Arctic region are only doubtfully distinct, and the gradation of one species into another is still only very partly understood; as an example, the shells now described as *Productus cancrini germanicus* were originally referred by Frebold to *P. cf. cancriniformis*, a distinctly earlier species. The whole problem of the Arctic Permian seems to hang on the study of facies-differentiation of contemporaneous faunas, and the reappearance of faunas of similar appearance at different horizons. A parallel may perhaps be adduced in the persistent nature of the "reef-knoll" facies in the Dinantian of Western Europe.

Recently Mirčink (1937) has separated the brachiopod fauna of the Kazanian into two groups of different origin: one found in the central Volga region, comprising a small fauna derived from Lower Permian relict types, and one in the north comprising many species derived from the late Palaeozoic ocean-basin Scandic. Dealing with this northern area he remarks: "Der Bestand der Fauna aus den stratigraphisch höher gelegenen Anlagerungen des pinegaschen Zechsteins trägt einen älteren charakter." It is at present uncertain how far this affects the problem being discussed.

Frebold (1933, p. 52 etc.), and Chabakov (1928) have indicated that the similarly-named species of *Productus* of the German Zechstein and the Russian Kazanian are not identical, and Frebold has indicated that the Greenland Zechstein species, and the variety of *Pr. cancrini* from the Brachiopodenkalk, are of German type. Frebold also suggests that the base of the German Zechstein is distinctly older than that of the Kazanian. This difference now appears much less marked and it is possible that the Greenland and N.W. European Zechstein on the one hand, and the Russian Kazanian on the other, are perhaps parallel developments in shelf-seas of the same physico-chemical nature, and that differences noted between elements in their faunas may be indicative of independent parallel adaptation rather than of markedly different age.

TABLE

	TEXAS	GREENLAND	ENGLAND	GERMANY	RUSSIA
yclolobus . *imorites* .	Capitan	Zechstein Martiniengest. Brach.-Kalk. Posidonomya-schiefer	Mag. Limestn. Marl Slate Yellow Sands	Zechstein Kupferschiefer Zechstein Cong.	Tartarian Kazanian
Vaagenoceras *errinites* .	Word Leonard-Hess				Kungurian Artinskian
roperrinites	Wolfcamp				Sakmarian (*Schwagerina*)

N.B.—In this table the three divisions of the Permian, with their zone-ammonoids, re taken from the work of Miller and Furnish, with whose views on the Carboniferous-ermian boundary the writer is in general agreement. There are still too many ncertainties in the age-determination of the higher Permian of Russia to allow of more ian very tentative correlation of these strata. Certain recent writers have suggested iat the Kazanian is younger than the Zechstein ; the evidence is poor, and at the iost indicates only that the strata are of slightly different age. The Zechstein may ctually be younger than the Kazanian. No exact equivalence of the Russian strata oove the Artinskian is intended in the table.

An attempt is made in the table to correlate the evidence discussed in this paper. The basis is the series of ammonoid-zones used by Miller and Furnish (1940), with the standard stratigraphical columns of Texas and Russia as other points of reference. The table is only tentative, and much further work needs to be done. Only a thorough revision of the stratigraphy and faunas of the Arctic " Permo-Carboniferous " and Permian will show whether this arrangement can be regarded as satisfactory.

Finally, it may be pointed out that the history of " *Godthaabites*. " is an interesting example of the pitfalls of dealing with juvenile ammonoids as stratigraphical indices. The nucleus of *Cyclolobus* so closely resembles that of earlier genera that Frebold seemed quite justified in assigning a much earlier age to the Martiniengestein than is indicated by full-grown shell.

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[1] Not available to the writer.

Age Determination of Carboniferous Basic Rocks of Shropshire and Colonsay

PART I

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PART II

By ARTHUR HOLMES, University of Durham

Part I.—Helium Method and Results

THE helium method of determining the ages of fine-grained basic igneous rocks has now been so far developed as to be applicable to various geological and petrological problems, particularly where geological periods are involved, as in the problem here discussed. For details of the history of this development up to the beginning of 1937 reference may be made to Holmes, 1931; Urry, 1933; Lane and Urry, 1935; Urry, 1936 (*b*); Holmes and Paneth, 1936; and Holmes, 1937. During 1937 it was found that many of the helium-ratios on which the "helium" time-scale had been based were too high, because of a previously unsuspected error in radium determination due to reliance having being placed on a radium standard which was seriously at fault. To clear up this embarrassing situation an immediate effort was made by several investigators in collaboration, and the first fruits of their work have recently become available (Evans, Goodman, Keevil, Lane, and Urry, 1939).

In the present communication an application of the method to the determination of the geological age—hitherto uncertain—of the monchiquite dykes of Colonsay is recorded. For comparative purposes the "helium" ages of two Carboniferous basic rocks from Shropshire[2] have also been measured. Petrological and other details of the rocks are provided in Part II by Professor Holmes, who suggested the investigation and supplied the specimens.

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[1] This research was undertaken and completed at the Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.

[2] The first determinations of these ages, published in the Shrewsbury Memoir of the Geological Survey of Great Britain, 1938, Ap. VI, p. 282, and by Holmes in *The Age of the Earth*, 1937, p. 125, are now withdrawn in favour of the revised values given in Table I of this paper. The earlier results were obtained before the above-mentioned error in the radium determinations had been detected. The results for He and Th remain as before.

The most serious objection that might be raised against the validity of the helium method is that the accumulating helium, being a gas, might migrate through the bulk of the rock mass and, in part, escape to the atmosphere. In view of the discrepancy between the " helium " time-scale and that based on lead-ratios which has now been established (Evans, *et aliter*, 1939), work on this problem is being actively pursued. Nevertheless, in our final Table VI, which summarizes some of the more recent comparable results on specimens of known geological age, the sequence of the " helium " ages is still found to correspond with that to be expected from the field evidence.

The principle of the method is, in simple terms, that if a certain amount of UI, AcU, and Th generates a certain number of helium atoms in a given time, say one year, as measured in the laboratory, then t'' years must have been required to produce the helium found to have accumulated in a rock from the radio-elements present. The actual computation, however, is complicated by the fact that the present-day content of the radio-elements is necessarily less than at time $t'' = 0$. The general solution for t, the geological age of a specimen in years, has been derived. Its arithmetical solution is tedious, however, and in practice it is unnecessary, since the uncertainties of measurements and assumptions regarding the past history of the specimen exceed by far the difference between the value derived from the general solution for t and that derived from simplified equations for t' or t''. The simplest approximate equation, which is only a quantitative statement of the principle of the method is :—

$$t'' = \frac{8{\cdot}74 \times 10^6\text{He}}{\text{U} + 0{\cdot}27\text{Th}} \text{ (years)} \ldots\ldots\ldots\ldots (1)$$

Equation (1) assumes a constant U and Th content over the geological time t''. Although this assumption is obviously incorrect, the proportion of U and Th atoms disintegrating is so small that equation (1) is adequate up to $t'' = 100$ million years. When allowance is made for the decrease of U and Th with increase of time, equation (2) is obtained. For its derivation see Urry, 1933.

$$t' = 1{\cdot}515 \times 10^{10} \log_{10} \left[1 + \frac{4{\cdot}515 \times 10^{-10}\text{He}}{\text{Ra} + 9{\cdot}17 \times 10^{-8}\text{Th}}\right] \ldots\ldots\ldots\ldots (2)$$

In equation (2) radium has been substituted for uranium, using the equilibrium constant $\text{Ra}/\text{U} = 3{\cdot}40 \times 10^{-7}$. Equation (2) differs from the general solution for t in neglecting (*a*) the difference in rate of disintegration between the uranium series

TABLE I.—HELIUM, RADIUM, AND THORIUM CONTENTS AND CORRESPONDING "AGES" OF THE ROCKS INVESTIGATED

Sample	He × 10^5 *cc/g*	Ra × 10^{12} *g/g*	U × 10^6 *g/g*	Th × 10^6 *g/g*	"Helium" Age in m.y.[1]
Little Wenlock Olivine-basalt					
A	2·32	0·39	1·14	1·02	140
Clee Hills Analcime-dolerite					
B	2·94	0·51	1·50	1·47	135
Kilchattan Monchiquite					
C	2·84	0·35	1·04	2·58	140
D	3·31	0·43	1·26	2·97	140
E	2·16	0·34	1·01	2·65	110
F	2·31	0·35	1·02	2·65	115
G	—	—	—	—	90
H	1·7	0·32	0·98	3·42	80
			Mean (C *to* F)		*125*
			Mean (C *to* H)		*110*
Riasg Buidhe Monchiquite					
J	6·91	1·05	3·06	6·12	125
K	8·86	1·19	3·50	7·20	140
L	6·61	1·01	2·98	5·41	130
M	6·26	1·10	3·24	5·30	120
N	—	—	—	—	100
O	—	—	—	—	110
			Mean (J *to* M)		*130*
			Mean (J *to* O)		*120*

A. *Olivine-basalt*, Horsehay Quarry, Little Wenlock, Shropshire. Flow of Lower Carboniferous age (D$_2$). *Lab. No.* Ho/1.
B. *Analcime-olivine-dolerite*, Titterstone Quarry, near Giant's Chair, Clee Hills, Shropshire. Sheet of Upper Carboniferous age (Yorko-Staffordian). *Lab. No.* Ho/5.
C. *Biotite-monchiquite*, Kilchattan Dyke, Island of Colonsay, Argyllshire. Collected 1934. *Lab. No.* Ho/K1.
D. Second specimen from the same dyke. Collected 1936. *Lab. No.* Ho/K2.
E. Second sample from the same hand specimen as C. Analysed two years later (1938).
F. Second sample from the same hand specimen as D. Analysed two years later (1938).
G. Sample from the same hand specimen as D. Age determined by C. Goodman by the alpha-particle counting method (*in* Evans, *et aliter*, 1939).
H. Sample from the same hand specimen as D. Determinations by N. B. Keevil (*in* Evans, *et aliter*, 1939).
J. *Monchiquite*, Riasg Buidhe Dyke, Island of Colonsay. Collected 1934. *Lab. No.* Ho/R1.
K. Second specimen from the same dyke. Collected 1936. *Lab. No.* Ho/R2.
L. Second sample from the same hand specimen as J. Analysed two years later (1938).
M. Second sample from the same hand specimen as K. Analysed two years later (1938).
N. Sample from the same hand specimen as K. Age determined by C. Goodman by the alpha-particle counting method (*in* Evans, *et aliter*, 1939).
O. Sample from the same hand specimen as K. Determinations by N. B. Keevil (*in* Evans, *et aliter*, 1939).

[1] The maximum calculated probable error of the individual values is ± 10 per cent of the age.

and the actino-uranium series, and (*b*) the dependence upon t' of the factor for converting Th to its equivalent U-value in terms of helium production. t' is within 5 per cent of the general solution value, t, for ages less than 1,000 million years.

The experimental problem is the determination of minute quantities of He, U, and Th of the orders recorded in Table I, these particular figures being representative for basic rocks as a whole. The details of the three independent determinations have been fully described in the literature (e.g. Urry, 1933 and 1936 (*a*), and references therein to methods of helium determination by F. A. Paneth and his co-workers).

The analytical data and computed " helium " ages (from equation 2) for two Carboniferous basic rocks and for the two monchiquite dykes of Colonsay are given in Table I. Previous experience of the heterogeneous dispersion of U and Th in rock material had already shown that it is advisable, and often imperative, to determine He, Ra, and Th in the same sample. This has been done in all the cases here reported. The two sets of Colonsay results clearly demonstrate the necessity for this restriction. From the evidence of the revised " helium " time-scale which appears on page 60, amplified by the two Carboniferous determinations of Table I, the Colonsay monchiquite dykes are to be placed chronologically in the late Carboniferous or Permian. This single example is illustrative of possible future accomplishments in the solution of geochronological problems. Much further work will still be necessary, however, before it becomes possible to differentiate between subdivisions of the periods.

Part II.—Geological Relations and Petrology

CARBONIFEROUS LAVAS OF SHROPSHIRE

The two specimens of which Dr. Urry has determined the " helium " ages were from a representative set of Midland " basalts " kindly collected for us by Dr. R. W. Pocock in response to a request for samples suitable for the application of the helium method. Those selected for the investigation were chosen because they were of compact grain, free from fractures and signs of weathering, of different and closely defined geological ages, and sufficiently large to provide ample material for all the purposes required.

The *Olivine-basalt of Little Wenlock* has been admirably described by Pocock (1926), whose observations have finally settled the long controversy as to its nature (lava-flow or sill) and age (Carboniferous or Tertiary). In the quarry at Horsehay from which the analysed specimen was collected, the basalt is exposed to a depth of fifty feet. In this section the rock of the lower forty feet is compact and fresh, but the upper part is vesicular and strongly weathered and is surmounted by Middle Coal Measures sandstone. In Lydebrook Dingle a conglomerate that forms the local base of the Coal Measures rests directly on the basalt and itself contains blocks of decomposed basalt. Elsewhere, the flow reaches a thickness of about a hundred feet, and lies between two beds of limestone, each of which represents a horizon low down in the D_2 sub-zone. The extrusive character of the basalt is proved by the occurrence of slaggy surfaces, local suggestions of pillow structure, absence of contact metamorphic effects on the adjacent sediments, and absence of transgression. The geological age of the flow is therefore well established as early D_2.

A general account of the petrography of the basalt was contributed to Pocock's paper (1926, pp. 154–5) by Thomas, who describes the fresh rock as a micro-porphyritic olivine-basalt of Dalmeny type. The analysed specimen of the present investigation corresponds exactly with this diagnosis. It contains micro-phenocrysts (1–2 mm.) of sparsely scattered plagioclase and augite, and of more abundant olivine and serpentine, in an intergranular groundmass. The plagioclase is labradorite (near An_{65}; highest refractive index = 1·57), peripherally zoned to oligoclase. The augite is zoned in tints of purplish fawn and greenish buff and, like the olivine, it contains included specks of black ore. The olivine is partly present as fresh cores (negative, with 2V near 90°) within subhedral forms that are veined and rimmed by green serpentine, some bands of which are thickly strewn with ore-dust. Most examples, however, have been further altered to a mottled ferriferous serpentine which is free from ore-dust. This variety is pleochroic in various tints of yellowish brown and brownish green and has a birefringence only a little lower than that of augite; it is therefore probably bowlingite or a related species. Relics of the earlier veins of ore-powdered green serpentine still persist in these composite pseudomorphs. The groundmass consists of an interlacing plexus of plagioclase laths (labradorite, with margins rapidly zoned to oligoclase), interspersed with prismoids and granular aggregates of faintly fawn-green augite, grains of olivine and its bowlingite-like alteration product, rods and angular specks of black ore, and vermicular blebs of a chloritic mineral; the interstices being occupied partly by alkali felspar with undulatory extinction, and partly by a pale buff serpentinous mineral.

A detailed chemical analysis of the rock has been made by Dr. F. Hecht and the results are listed, together with the norm, in Table II. Comparison with the type Dalmeny olivine-basalt (Dixon, 1927) shows a close correspondence, except that in the latter Al_2O_3 is lower and MgO higher. See also MacGregor (1928, analyses IX, X and XI) for this and other analyses of Scottish olivine-basalts of Dalmeny type. The Little Wenlock olivine-basalt has the relatively high potash which is a general

TABLE II

OLIVINE-BASALT (DALMENY TYPE), HORSEHAY QUARRY, LITTLE WENLOCK, SHROPSHIRE

	Percentages.	*Molecular Proportions.*
SiO_2	46·94	·7816
Al_2O_3	16·39	·1608
Fe_2O_3	3·33	·0209
FeO	7·34	·1022
MgO	5·82	·1444
CaO	10·38	·1851
Na_2O	2·76	·0445
K_2O	1·64	·0174
H_2O+	2·07	—
H_2O-	·57	—
CO_2	·15	·0034
ZrO_2	·03	·0002
TiO_2	2·32	·0290
P_2O_5	·25	·0018
Cl	·034	·0010
S	·025	·0008
Cr_2O_3	·006	—
V_2O_3	·04	·0003
NiO	·013	·0002
CoO	·009	·0001
MnO	·17	·0024
BaO	·05	·0003
SrO	·033	·0003
CuO	·006	·0001
ZnO	·036	·0004
Rare Earths	·026 [1]	—
	100·44	
Less O	·02	
	100·42	

Norm.

Orthoclase			9·68
Albite			23·07
Anorthite			27·54
Nephelite			·17
Diopside	$CaSiO_3$	8·94	17·33
	$MgSiO_3$	5·64	
	$FeSiO_3$	2·75	
Olivine	Mg_2SiO_4	6·22	9·58
	Fe_2SiO_4	3·36	
Magnetite			4·91
Ilmenite			4·40
Pyrite			·05
Apatite			·61
Calcite			·34
Water			2·64
Rare Earths			·03
			100·35

III, 5, 3, 4 Camptonose.
Analyst: F. Hecht.

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[1] The rare earths are somewhat dubious. They were determined by the method of W. F. Hillebrand, but the precipitate was found to be white instead of coloured.

characteristic of the British Carboniferous-Permian basic rocks (Tomkeieff, 1937, pp. 62–3). In this and certain other respects it differs systematically from the basaltic rocks of the British Tertiary province. The Plateau and Non-porphyritic Central Magma Types have higher iron oxides and MgO and lower Al_2O_3 and K_2O. The Porphyritic Magma Type has lower iron oxides and alkalies (especially K_2O) and higher CaO and Al_2O_3.

The *Analcime-olivine-dolerite of the Clee Hills*, like the basalt of Little Wenlock, was formerly regarded as an intrusion of Tertiary age. Pocock (1931, pp. 4–6) has listed observations supporting the alternative view that the sheet may be a flow, but in this case the evidence is not altogether conclusive.[1] The evidence of age, however, is complete. The sheet ranges in thickness from about 30 to over 80 feet, and occupies a position about 180 feet above the highest known Yorkian horizon and 700 feet below the lowest known Staffordian horizon. At the Magpie quarry the occurrence of small pebbles of tachylyte in grey clay and grit occupying hollows in the surface of the sheet proves erosion in Yorko-Staffordian times. Thus, whether or not the sheet be extrusive or intrusive, it is clearly of Yorko-Staffordian age.

The analysed specimen has the aspect of a fresh, compact dolerite, with phenocrysts (up to 3 or 4 mm. across) of olivine and its serpentinous alteration products. Where fresh, the olivine is negative and shows a distinctly curved isogyre in sections normal to an optic axis, indicating that the olivine is richer in fayalite than that of the Little Wenlock basalt. This feature is also brought out by the norm. Many of the smaller olivines, and some of the larger ones, are partly or completely replaced by green serpentine with a low birefringence; most of the larger ones, however, are pseudomorphed by bowlingite-like material, resembling that already described, but often of a conspicuously darker brown colour. The slide examined also contains a patch—probably xenolithic—of nearly colourless serpentine, veined in green, which is pseudomorphous after an aggregate of crystals which, judging from the forms of two of them, were probably olivine originally. The aggregate has been invaded, and either disrupted or partially replaced, by tongues of analcime heavily sprinkled with minute grains of augite and containing a little calcite.

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[1] According to the observations of Dr. C. E. Marshall the sheet is intrusive. In a paper read before the Geological Society of London on 4th December, 1940, he writes: "the transgressive nature of the upper contacts and alteration of the overlying sediments cannot be denied."

The groundmass contains a smaller proportion of plagioclase than that of the Little Wenlock basalt. The laths are longer (up to 2 mm.), somewhat ragged in outline, and clearly zoned from labradorite to oligoclase; some of them pass almost imperceptibly—except for the change of refraction—into alkali felspar, which occupies part of the interstitial spaces. Here and there a mottled alkali felspar with undulatory extinction builds roughly rectangular plates (up to 2 × 1 mm.). Clusters of faintly purplish prisms and granules of augite are characteristic, though isolated crystals also occur among the felsic minerals. Against serpentine and bowlingite a peripheral crowding of minute grains of augite is very marked, and occasionally such grains may be seen inside these alteration products. In contact with analcime the augite sometimes develops green tips and fringes of aegirine-augite. A much more abundant green mineral, sporadically dispersed through the groundmass, with some concentration near mafic minerals, is probably serpentine. Angular grains and skeleton forms of titaniferous black ore, sometimes altered to leucoxene, are uniformly distributed. Where these are in contact with alkali felspar very minute scraps of biotite may occasionally be detected. As already indicated, the interstitial material includes alkali felspar and what may be serpentine, but analcime is more abundant than either of these. It occurs in turbid isotropic patches and wedges, shot through with needles of apatite and here and there enclosing traces of calcite.

The specimen has been analysed by Dr. Hecht, whose results, together with the norm, are given in Table III. They show that the rock differs from the Little Wenlock basalt in having higher Na_2O, H_2O, and MgO, corresponding to its higher content of serpentinous minerals and the abundance of analcime; and lower Al_2O_3 and CaO, corresponding to its lower content of plagioclase. Chemically the rock can be matched by many teschenites, though it is slightly deficient in alkalies compared with average teschenite (Guppy, 1931, p. 92, and Tomkeieff, 1937, p. 62). Against this, however, it may be noted that another analysis of the Clee Hills rock shows 4·23 per cent of Na_2O and 1·94 per cent of K_2O (Reade and Holland, 1907). In a frequently quoted old analysis (Player) the respective percentages of these constituents are 3·1 and 2·1. Compared with crinanite (Walker, 1934, p. 126), the alkalies are much higher, with potash about five times as high. Geochemically the rock falls naturally into the British Carboniferous province.

TABLE III

ANALCIME-OLIVINE-DOLERITE, TITTERSTONE QUARRY, CLEE HILLS, SHROPSHIRE

	Percentages.	*Molecular Proportions.*
SiO_2	47·32	·7879
Al_2O_3	14·51	·1423
Fe_2O_3	2·44	·0153
FeO	8·51	·1185
MgO	6·93	·1719
CaO	8·68	·1548
Na_2O	3·54	·0571
K_2O	1·51	·0160
H_2O+	2·92	—
H_2O-	·57	—
CO_2	·13	·0030
ZrO_2	·03	·0002
TiO_2	2·20	·0275
P_2O_5	·23	·0016
Cl	·015	·0004
S	·039	·0012
Cr_2O_3	·023	·0002
V_2O_3	·035	·0002
NiO	·009	·0001
CrO	·007	·0001
MnO	·16	·0023
BaO	·035	·0002
SrO	·031	·0003
CuO	·007	·0001
ZnO	·019	·0002
Rare earths	trace	—
	99·90	
Less O	·02	
	99·88	

Norm.			
Orthoclase			8·91
Albite			25·88
Anorthite			19·26
Nephelite			2·20
Diopside	$CaSiO_3$	9·07	17·65
	$MgSiO_3$	5·49	
	$FeSiO_3$	3·09	
Olivine	Mg_2SiO_4	8·25	13·76
	Fe_2SiO_4	5·51	
Magnetite			3·63
Ilmenite			4·18
Pyrite			·05
Apatite			·54
Calcite			·30
Water			3·49
			99·85

III, 5, 3, 4. Camptonose.
Analyst: F. Hecht.

MONCHIQUITE DYKES OF COLONSAY

The two monchiquite dykes of Colonsay belong to a sporadic suite of monchiquite and camptonite dykes, commonly following a north-west trend, of which members have been found in Coll, Iona, the Ross of Mull, Scarba, Morven, Ardmucknish, and other parts of Argyllshire. A map showing the chief localities is given in the Mull Memoir, p. 357. Although on grounds of petrographic analogy all these dykes are thought to be of the same age, their geological relations nowhere provide direct evidence of what that age may be, beyond the probability that it is post-Carboniferous (Flett, 1911, p. 41). Of the Colonsay monchiquites no more can be said than that they cut formations regarded as Torridonian. The approximate parallelism of these dykes to the north-west dolerite dykes of Colonsay suggested to Wright and Bailey (1911, p. 8) that they might belong to the same "presumably Tertiary" suite. The following year Tyrrell (1912, p. 78) recorded a late Carboniferous or Permian monchiquite from Carskeoch Hill, near Patna, Ayrshire, and noted its similarity to that of Kilchattan. In his *Presidential Address* of 1917 Harker (1918, p. lxxxvi) suggested the probability that the monchiquites of the isles and littoral of Argyllshire might be of late Palaeozoic age, like those of Ayrshire and Fife. Later, Bailey recorded the fact that in Mull no monchiquite or camptonite dyke had been found cutting Mesozoic sediments or Tertiary lavas, though Tertiary dykes of dolerite or tholeiite were observed to cut the camptonites (1924, p. 378). Nevertheless at this time Bailey was still "inclined to adopt the Tertiary hypothesis, with the proviso that most of the West Highland camptonites are amongst the earliest manifestations of the Tertiary magma". Returning to the problem a year later Bailey writes (1925, p. 81): "The petrological argument in favour of a Pre-Tertiary date for the camptonites, etc., is greatly weakened by the fact that no one can draw a sharp distinction between the camptonitic facies and the normal Tertiary types. . . . The point is obviously a very difficult one." Referring to the monchiquite and camptonite dykes of Coll, Bailey, Eyles, and Simpson (1930, p. 358) summarize the position by stating: "The question of age cannot, however, be decided on any evidence that has been obtained up to date." They are sympathetic to the suggestion that "it is natural on petrographical grounds to class them with the Permian rocks of Western Scotland as exemplified in Ayrshire".

In view of the petrogenetic importance of solving the problem, the occasion was taken in 1934, during field work in Colonsay, to collect fresh specimens of the monchiquite dykes in the hope that Dr. Urry would determine their helium-ratios. This he kindly agreed to do, but as two years elapsed before the analytical work was undertaken, another set of specimens was collected in 1936 and two large blocks were immediately despatched to Dr. Urry, who then made the analyses at once. The agreement between the ratios for the 1934 and 1936 specimens analysed in 1936 and again in 1938, as indicated by the computed "ages" (Table I), shows that no appreciable amount of helium escapes. The direct demonstration that the Colonsay monchiquites are of late Palaeozoic age proves Harker's suggestion to have been correct for these two cases, and thus adds powerful support to the probability of its general validity for the area west and north-west of the Midland Valley.[1]

The *Kilchattan Dyke* (*Biotite-monchiquite or Ouachitite*) can be readily found in the crags of Kilchattan grits and phyllites that rise to the east of the easternmost cottages of Lower Kilchattan. The dyke follows a nearly S.E. trend as far as the stepping-stones across a small stream from Dubh Loch, whence it can be traced across the moorland in a more S.S.E. direction. The analysed specimens were collected from conspicuous outcrops due west of Dubh Loch.

The matrix of the rock is extremely fine-grained but, except marginally, it contains a great variety of xeno-porphyritic crystals and other xenolithic material, somewhat concentrated in bands. The most conspicuous minerals are plates of biotite (up to 4 cm. across), aligned parallel to the walls of the dyke; less abundant prismatic hornblende (up to 6 × 2 cm.); and smaller masses of augite, generally enclosing biotite. All of these have rounded and sometimes embayed outlines, with margins and invasive tongues of reaction products, but internally most of them are fresh and lustrous. They have been described by Flett (1911, p. 44), who also records the occurrence of an irregular crystal of apatite nearly half an inch in length, and of a corroded " composite phenocryst " of biotite intergrown with augite that is heavily charged with minute grains of black ore. Through the kindness of the Survey authorities I have been allowed to see the slide (No. 13626/2) in which this " composite phenocryst " occurs. There is nothing in the slide itself to show the origin of the material (it is not biotite-pyroxenite), but other sections show that it is a reaction product from a xenocryst of biotite. To the list of xenolithic constituents may now be added the following: biotite-pyroxenite in several varieties; glimmerite; olivine-pyroxenite; spinel-peridotite, largely carbonatized; aggregates of pale augite and brown hornblende; fragments of titaniferous magnetite; and relics of altered sediment and gneiss. Similar xenolithic materials are highly characteristic of the monchiquites of the Midland Valley and have been described by Tyrrell, Mrs. Wallace, Balsillie, Walker, and others, as well as by the Survey geologists (see Macgregor and MacGregor, 1936; the map facing p. 63 shows the chief localities and a good bibliography appears on pp. 68–9).

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[1] Since this paper was written in 1937, Richey (1939, pp. 416–19) has published a general account of the dykes of Scotland. In this he considers the camptonites and monchiquites, from the Orkneys in the north to the Sanquhar Coalfield in the south, to be of Permian age. An excellent map showing the distribution and trends is provided.

The matrix contains minute prisms of very pale or fawn-tinted augite, evenly distributed; scales of red-brown biotite, tending to occur in clusters; grains and octahedra of black ore, accompanied in some sections by grey-brown sphene; all embedded in a clear or slightly turbid mesostasis of analcime, locally associated with specks of calcite, needles of apatite, traces of nepheline and patches of zeolitic material, shreds of aegirine-augite, and greenish areas suggestive of chlorite. The matrix is variegated by ocelli, commonly 1 or 2 mm. in diameter, but sometimes larger, containing analcime, with or without carbonates; fan-like tufts of alkali felspar; blades and skeletal forms of biotite, occasionally outlined with chlorite and sometimes arranged radially or tangentially; and prisms of purplish augite in a zig-zag or radial disposition. Besides the ocelli there are relatively large and small leucocratic patches of highly irregular and variable form. These contain the same minerals as the ocelli, but are usually more coarsely crystalline; some of them are comparatively rich in purple augite.

Radley's analysis of the biotite-monchiquite is here reproduced, together with the norm, in Table IV. The analysed sample—of which I have been allowed to examine the remaining portion

Table IV

BIOTITE-MONCHIQUITE, LOWER KILCHATTAN DYKE, ISLAND OF COLONSAY, ARGYLLSHIRE

	Percentages.	*Molecular Proportions.*
SiO_2	39·54	·6583
Al_2O_3	13·74	·1348
Fe_2O_3	4·05	·0254
FeO	7·85	·1093
MgO	8·66	·2148
CaO	9·64	·1719
Na_2O	2·24	·0361
K_2O	3·70	·0393
H_2O+	2·77	—
H_2O-	·61	—
CO_2	2·48	·0564
TiO_2	2·72	·0340
P_2O_5	1·01	·0071
Cl	·00	—
FeS_2	·27	—
$(Ni, Co)O$	·05	·0007
MnO	·40	·0056
BaO	·19	·0012
SrO	·14	·0014
Li_2O	·00 ?	—
	100·06	

Norm.			
Orthoclase			21·87
Albite			5·71
Anorthite			16·52
Nephelite			7·16
Diopside	$CaSiO_3$	4·07	7·80
	$MgSiO_3$	2·81	
	$FeSiO_3$	·92	
Olivine	Mg_2SiO_4	13·14	18·15
	Fe_2SiO_4	5·01	
Magnetite			5·88
Ilmenite			5·16
Pyrite			·27
Apatite			2·39
Calcite			5·64
Water			3·38
			99·93*

* Low total is due to reckoning BaO and SrO as CaO.

III, 6, 3, 3. Ourose.

Analyst: E. G. Radley (*Colonsay Memoir*, 1911, p. 46).

—is typical of the middle part of the dyke and contains representative examples of all three of the dominant xenocrysts: biotite, hornblende, and augite. It should be noted here that the specimens sent to Dr. Urry for age determination were specially selected for the paucity of these minerals, in order to reduce to a minimum any tendency towards loss of helium along cleavage cracks or fractures. It is hoped in a later detailed petrogenetic study of the dyke to present separate analyses of matrix and xenocrysts. Meanwhile, it is of interest to notice that the general composition of the rock corresponds closely with that of (*a*) the biotite-leucitite of Visoke in the Birunga volcanic field, a lava which seems to have resulted from the "invasion and partial transfusion of biotite-pyroxenite by a subsequent magma" (Holmes and Harwood, 1937, p. 85, and analysis No. 44); and (*b*) the sannaite of the explosion pipe of Ormen, Oslo District, regarded by Brögger (1921, p. 186) as a mixture of vibetoite (calcite-bearing hornblende-biotite-pyroxenite) with material of fenite-juvite composition, the latter being itself a product of the action on granite-gneiss of soda-bearing emanations followed by potash-bearing emanations.

The *Riasg Buidhe Dyke* (*Monchiquite*) outcrops conspicuously in the cliffs on the northern side of Port a' Bhàta, due east of the deserted village of Riasg Buidhe, north-east of Scalasaig. It cuts vertically through the Kiloran Flags and from the top of the cliff it can be picked up at intervals for a hundred yards or so, near and parallel to an old wall that runs inland in a north-westerly direction.

The rock contains xeno-porphyritic crystals like those of the Kilchattan dyke, but smaller in size and fewer in proportion; in addition it contains xenocrysts and aggregates of serpentine after olivine. The xenolithic augite is of three kinds: colourless to faint green (in thin section), like that of the Kilchattan dyke; brighter green; and purplish brown. All have reaction borders of the fawn to faintly green type that occurs as micro-phenocrysts in the body of the rock. Other noteworthy xenolithic constituents are various types of pyroxenite (with only traces of biotite), and of aggregates of enstatite-augite-olivine-picotite, some examples of which are perfectly fresh, while others are largely replaced by green bowlingite and carbonates. Picotite-bearing lherzolites have been described as xenoliths from several of the monchiquites and related lavas from the Midland Valley (Tyrrell, 1918, pp. 348, 350, and 358–360).

The groundmass resembles that of the Kilchattan dyke, but with the addition of small (1 mm.) micro-phenocrysts of greenish fawn augite, some of which have xenolithic cores of other types; platy biotite; and bowlingite, with or without calcite, probably pseudomorphous after olivine. The bowlingite is identical with that in the lherzolite-like xenoliths, from which it may possibly be derived. The mesostasis is mainly analcime, commonly accompanied by calcite and locally by serpentine; it is copiously shot through by apatite needles. Ocelli and irregular leucocratic patches occur, as in the Kilchattan dyke, but felspar has not been detected. A little pyrite occurs with calcite in some of the ocelli.

A characteristic specimen of the dyke was analysed by the late Lady Gibbs, whose results, together with the norm, are listed in Table V. The composition of the rock differs from that of Kilchattan in having more Na_2O and H_2O and less K_2O, corresponding mineralogically to the higher analcime (and bowlingite) and lower biotite contents; higher CaO and TiO_2, corresponding to the greater abundance of augite and hornblende, relative to biotite; and lower SiO_2, corresponding in part to the lack of felspar. The results in Table I indicate a

TABLE V

MONCHIQUITE, RIASG BUIDHE DYKE, ISLAND OF COLONSAY, ARGYLLSHIRE

	Percentages.	*Molecular Proportions.*
SiO_2 . .	37·03	·6166
Al_2O_3 . .	13·66	·1340
Fe_2O_3 . .	4·81	·0301
FeO . .	7·59	·1057
MgO . .	8·44	·2093
CaO . .	10·99	·1960
Na_2O . .	3·18	·0513
K_2O . .	2·22	·0236
H_2O+ . .	3·93	—
H_2O- . .	·51	—
CO_2 . .	2·12	·0482
TiO_2 . .	3·12	·0391
P_2O_5 . .	1·38	·0097
F . . .	·12	·0063
S . . .	·21	·0066
Cr_2O_3 . .	trace	—
V_2O_3 . .	·01	·0001
NiO . .	trace	—
MnO . .	·19	·0027
BaO . .	·21	·0014
SrO . .	·34	·0033
	100·06	
Less O . .	·13	
	99·93	

Norm.			
Orthoclase . . .			13·13
Albite			5·24
Anorthite . . .			16·44
Nephelite . . .			11·73
Diopside	$CaSiO_3$	7·10	13·52
	$MgSiO_3$	5·22	
	$FeSiO_3$	1·20	
Olivine	Mg_2SiO_4	11·07	13·79
	Fe_2SiO_4	2·72	
Magnetite . . .			7·00
Ilmenite . . .			5·93
Pyrite			·40
Apatite . . .			3·26
Calcite . . .			4·82
Water			4·44
			99·70*

* Low total is due to reckoning BaO and SrO as CaO.

III, 6, 3, 4. Limburgose.

Analyst: Agnes Gibbs.

remarkable difference in the content of radio-elements. The Riasg Buidhe rock contains three times as much uranium and twice as much thorium as that of the Kilchattan dyke. Apart from this peculiarity, which has not as yet been investigated, comparison of the xenolithic constituents of the two dykes suggests that these are largely responsible for the differences in composition, and that the active magmatic material immediately responsible for the formation of the dykes was much richer in soda than either of the resulting rocks.

The analysed Midland Valley monchiquitic rocks all have higher silica than those of Colonsay, but some of those of the Orkneys have less, and approach the alnöites (Flett, 1935, pp. 182–6). It is of interest to notice that some of the monchiquites of the Monteregian province (Washington's *Tables*, 1917, p. 912), are fairly close analogues of the Riasg Buidhe example.

AGE-CORRELATION OF THE COLONSAY MONCHIQUITES

In Table VI the most recent geochronological data covering the Pliocene to Devonian periods are listed (after Urry, 1936 (*b*), with revision to date). The helium ages are calculated from formula (2) on page 46. Judged by the helium method, the Colonsay results (125 and 130 m.y.) clearly fall into the gap between Triassic (mean value, 100 m.y.) and Carboniferous (135 and 140 m.y.). It will be seen that only Urry's results have been used in making this comparison, since the values obtained by Goodman and Keevil are systematically lower (cf. Table I). This difference extends to rocks of other periods and its meaning has as yet not been satisfactorily cleared up (Evans, *et aliter*, 1939, p. 942). Since the helium method time-scale here given is internally consistent, it may be concluded that the Colonsay monchiquites are of late Carboniferous or Permian age, with considerable probability in favour of the latter. There is now good positive evidence that they belong to the same period of magmatic activity as the alkali igneous rocks of the Permian provinces of Oslo and the Midland Valley of Scotland.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Dr. R. W. Pocock for collecting and supplying specimens of Midland " basalts " suitable for age determinations, and to the authorities of the Geological Survey for permission to examine thin sections, and also the analysed specimen, of the Kilchattan dyke. By the

TABLE VI

A REVISED HELIUM METHOD TIME-SCALE

Geological Age	Rock Type and Locality	No. of Results [1]	Millions of Years on the "Helium" Scale
Pliocene . .	Basalt, Flow in S.E. Oregon, U.S.A.	1	8
Miocene .	Basalts, Flows in Douglas Creek and Columbia River Canyon, State of Washington, U.S.A.	3	10
Oligocene .	Basalts, Lower Silesia, Europe .	3	20
Cretaceous-Jurassic.	Granodiorites and associated intrusives, Grass Valley, California, U.S.A.	5	60
Triassic . .	Dolerite sill, West Rock, New Haven, Conn., U.S.A.	3	93
	Dolerite sill, Palisades, New Jersey, U.S.A.	3	100
	Basalt, Cape Spencer Flow, Nova Scotia.	1	100
	Basalt, Oldest Flow of Watchung Mt., New Jersey, U.S.A.	1	105
(Post-Torridonian).	*Monchiquite dyke, Riasg Buidhe, Colonsay.* Mean (C to F).	4	125
	Biotite-monchiquite dyke, Kilchattan, Colonsay. Mean (J to M).	4	130
Upper Carboniferous.	Analcime-olivine-dolerite, Clee Hills, Shropshire.	1	135
Lower Carboniferous.	Olivine-basalt, Little Wenlock, Shropshire.	1	140
Devonian .	"Newbury Volcanic Rock," Rowley, Mass., U.S.A.	1	180

lamented death of Lady Gibbs, since Part II of this paper was written, we in Durham have lost a dear friend and a most valued collaborator. The chemical analysis of the Riasg Buidhe monchiquite which she contributed some years ago is only one of many analyses for which we are indebted to her skill and generosity.

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[1] Except in the case of the Colonsay dykes, more than one individual result signifies specimens from different localities. A probable error of ± 10 per cent may be assigned, although some results and particularly values based on a series of results have a considerably lower calculated probable error.

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On Gill-like Structures in the Eurypterida

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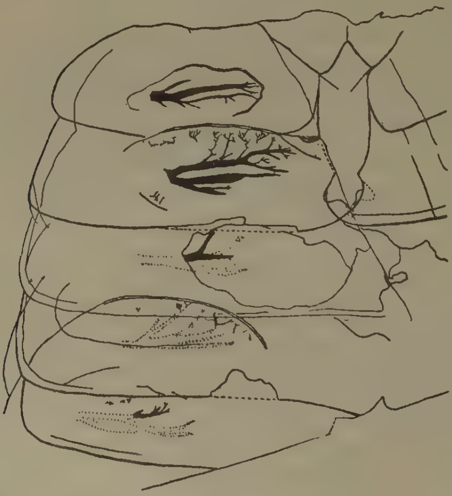
INTRODUCTION

(PLATE I)

THE nature and arrangement of the " gills " of Eurypterids is not known in detail. A specimen of *Slimonia* in the Sedgwick Museum (No. A16237a), figured by Laurie (1893, pl. 1, figs. 5, 6, p. 514), seems to show their structure and segmental arrangement better than any described elsewhere. Owing to the rather poor quality of Laurie's figure and to the important conclusions which follow a study of this specimen, it has been thought fit to re-describe it here.

DESCRIPTION OF SPECIMEN (Pl. I, Figs. 1 and 2, Text-fig. 1).



TEXT-FIG. 1.—A figure of the specimen of *Slimonia acuminata* described in this paper, partly restored. The figure represents the right half of the mesosoma in ventral view. Dotted or broken lines indicate attempted restoration. × ⅛ approx.

The specimen and counterpart (A16237a and b) comprise parts of two individuals of *Slimonia acuminata* (Salter) (b 142, b 126, in *Cat. Camb. Sil. Geol. Mus. Cambridge*, Salter, 1873).

One individual shows the dorsal surface of the prosoma, the other shows the ventral surface of the prosoma (approx. length 135 mm.), and a large part of the mesosoma. The mesosoma of the latter will be described.

The maximum length of the mesosoma is estimated at 180 mm. and half the width is 122 mm. at the posterior margin of the opercular plate.

The genital operculum, parts of four pairs of abdominal plates (sometimes known as sternites), five gills on the right side, and portions of the tergites are visible. The operculum is of type A. The first pair of abdominal plates are not fused but overlap in the centre line. At the anterior margin of the right plate, close to the median appendage, is a small area of crescentic folds. Attention is drawn to this because they closely resemble in appearance folds described by Störmer (1936, p. 30, pl. xii, fig. 1) as muscle attachments, though those figured by Störmer were on the dorsal side and nearer the outer margin.

The succeeding abdominal plates are probably fused in the mid-line.

Traces of five gills can be seen on the right side of the animal. The outline of each gill is that of an irregular oval lying nearly in the centre of the corresponding abdominal plate. The long axes are inclined slightly forwards towards the centre line (at about 5° in the second gill), the anterior margin is in each case better defined than the posterior.

The surface is marked by thickenings with an arborescent pattern which varies from gill to gill. It consists of two or three main trunks which arise at the outer end of the gill, at a point about two-thirds of the way out from the centre line of the mesosoma. These trunks run more or less parallel to the long axis of the gill and bear finer branches which divide repeatedly, giving an almost reticulate appearance to the margins of the gills.

The first gill lies entirely under the operculum. The outline is that of an irregular oval (long axis 50 mm., short axis 19 mm.) and is clearly marked by a marginal groove. The origin of the arborescent markings lies 34 mm. from the right margin of the operculum (a sixth of the total breadth of the operculum), and 16 mm. from the posterior margin (a third of its total length). There is a main trunk running more or less parallel to the long axis and tapering from 3·5 mm. to 0 mm. in diameter. Branches are given off from this which subdivide rapidly. Much of the detail of the finer markings is obscured by a cover of opercular scales, which demonstrate that the gill lies dorsal to the operculum.

The second gill is larger (long axis 74 mm., short axis 29 mm.), but not quite so well defined. It is level with, and presumably lies under, the first abdominal plate. The finer branching is very well shown.

Only traces of the third gill are seen since the abdominal plate has largely broken away displaying the tergite dorsal to it, and demonstrating that both tergites and abdominal plates are present in the specimen.

The fourth gill is impressed upon two segments. The anterior of these segments is dorsal to the second abdominal plate and must therefore be a tergite, probably the fourth. The posterior segment, together with the last segment of the mesosoma, which bear faint impressions of the fifth gill, may be either tergites or abdominal plates, the specimen is not sufficiently well preserved to determine their exact nature.

PREVIOUS DESCRIPTIONS OF GILLS IN THE EURYPTERIDA

Salter (1859, p. 50, pl. i, fig. 16) drew attention to " radiated muscular impressions " on a specimen described as *Pterygotus peronatus* var. *plicatissimus*. Woodward interpreted these structures as gills and redrew the specimen (1869, pl. xi, 2*a*, 2*b*). He also drew attention to the orientation of the scales and inferred that the operculum had been turned forward. Whether these were gills or not, the figures suggest that they were not on the operculum, but on the body wall dorsal to it. Woodward has drawn two gill-like structures on the left side, Salter only figures one. Woodward's views are summed up by his remarks on *Slimonia* (1872, p. 116) ; he considered the gills as " arranged in linear series and . . . attached in single or double rows to the underside of the body by their upper end . . . having probably been largest near the centre of the body, becoming smaller as they approached the sides ". He figured numerous structures which he claimed to be gills ; 1868, pl. x, 3*a*, 3*b*, pl. xi, 2*a*, 2*b* ; 1869, pl. xii, 1*a*, 1*d*, pl. xiii, 1*h* ; 1872, pl. xix, 3, 4.

Woodward then considered the gills to lie in rows across the body, with their long axes parallel to that of the animal. The gills figured in 1868, pl. x, 3*a*, 3*b*, thought by Woodward to represent part of such a row across the body, must, however, be interpreted as part of four segments of the mesosoma with the long axes of the gills parallel to the segmental divisions.

The distorted specimen of *Pterygotus* (1869, pl. xii, 1*a*) showed a gill, or gills, in the correct orientation, but Woodward apparently considered them to be rotated through 90° and in his enlargement (fig. 1*d*) they are drawn, with other structures which may only be irregularities in the abdominal plates, in a row across the page.

Laurie accepted Woodward's views on the gills of *Pterygotus* and considered that there was at least one lamella, probably more, on each mesosomal segment of *Slimonia*. He was the first to describe the specimen figured in this paper; he showed only two gills, though, as mentioned above, five can be distinguished.

Clarke and Ruedemann figure several examples of gills: 1912, pl. xiii, fig. 1 (*Eurypterus*); pl. xxv, fig. 1 (*Eurypterus*); pl. xxvi, fig. 2 (*Eurypterus*), this specimen shows the cordate outer end noted by Woodward; pl. xxix (*Eusarcus*), the latter is particularly interesting since it shows the first gill directly underlying the second tergite; and pl. xxxvii (*Eusarcus*).

Störmer (1933) shows gills in text-fig. 38, pl. vii, pl. v, fig. 1 (*Mixopterus*).

Holm figures examples in *Eurypterus fischeri* Eichw., e.g. 1898, pl. v, figs. 12 and 11; although in a different genus these bear a striking resemblance to those of *Slimonia* described in this paper. Pl. x, fig. 9, appears to be the inner side of the ventral half of the body. Gills are clearly visible as areas in a membrane which appears to be the body wall and not the abdominal plates (*vide infra*).

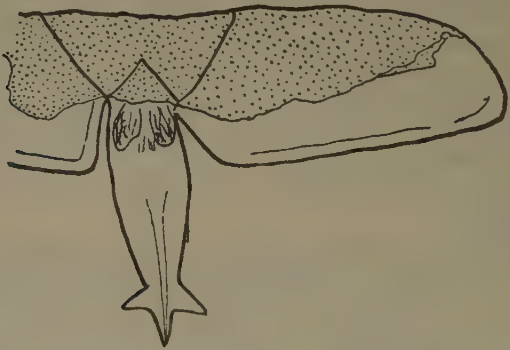
THE NATURE OF THE "GILLS"

These gills or similar structures were described as respiratory organs by Woodward, as branchial leaflets by Laurie, and indeed have been given a respiratory significance by most authors, including Clarke and Ruedemann, Lankester, Holm, and Störmer. However, Salter (1859, p. 50), had considered that a possible example which he saw represented muscle attachments, and Laurie writes that Professor Young had the same opinion about another specimen. Salter's example was apparently much distorted, and he considered the markings to be the points of attachment of the swimming feet. Young thought them to represent "the inner surface of a limb, with marks of muscle attachments" (Laurie, 1893, p. 514).

The writer has recently found structures on an operculum of *Slimonia* which are almost certainly muscle scars (Text-fig. 2).

The markings are quite different to those on the gills though the latter bear a superficial resemblance to the muscular areas, which might cause some confusion in ill-preserved specimens.

The idea of a respiratory function for the gills was probably suggested by the tree-like ridges observed on good specimens. These were interpreted as vascular markings by Woodward (1869, p. 68; 1872, p. 116), who was followed by Laurie (1893, p. 514). One would not expect a blood vessel to be preserved in relief in a fossil, being generally more compressible than the surrounding flesh, though in a soft vascular organ it is conceivable that the blood vessels might be the most resistant structures.



Text-fig. 2.—(Sedgwick Museum No. A16236.) A genital operculum of *Slimonia acuminata* (Salter). The stippled area indicates where the actual substance of the plate is preserved. Over the rest of the specimen it has broken away, leaving a very clear cast of the underside of the operculum. The muscle scars appear as oval areas, with irregular ridges, on either side of the median appendage, at its anterior end. × ½ approx.

Sometimes a soft part has its impression recorded on a growing chitinous organ covering it, and that may have happened in this instance.

Homology with the branchial lamellae of *LIMULUS*

The gills of Eurypterids have been compared with those of *Limulus*, and Woodward's conception of their attachment to the body was, perhaps, influenced by this idea. Woodward considered them to be homologous with the leaflets attached to the abdominal appendages of *Limulus*. Holm's preparations (1898, pl. v, figs. 11, 12) showed, however, that they were in the skin rather than attached to it by one end, and so he considered them to be areas of attachment (Kiemenplatt) from which might have hung gill lamellae (Kiemenblätter). It should be noted that the area of attachment in *Limulus* shows no trace of the complex venation observed in *Slimonia*, though of course some kind of blood supply must exist. In the numerous examples of gills which Holm prepared he found no trace of attached lamellae. He found one doubtful example of lamellae, unattached to the rest of the body (1898, p. 39, pl. iv, fig. 22), but he is himself very uncertain as to the true nature of this object. There is no evidence of such lamellae in the specimen here described.

The close resemblance in organization between Eurypterida and Xiphosura would suggest that gills, homologous with those in the Xiphosures, should be found in the Eurypterids.[1] But one is forced to the conclusion that the gills so far described in Eurypterids are not homologous with those of *Limulus*. There is no conclusive evidence of lamellae attached to them; their shape, structure, and particularly their position (*vide infra*) in no way resembles that of *Limulus*; the only similarity is in their inferred function.

POSITION OF GILLS

Holm inclined to the view that the gills were attached to the dorsal or inner surface of the operculum and abdominal plates, though he made it clear (1898, p. 38) that it was quite possible that they were in the skin of the body wall. Störmer also considers them attached to the inner surface of the operculum and abdominal plates, and Clarke and Ruedemann (1912, p. 67) had the same views. Laurie thought that the first gill was "attached to the soft skin of the body" (1893, p. 514), but that the others were borne on the inner side of the abdominal plates, (Holm rightly points out that this inconsistency is improbable). The writer's observations lead him to believe, however, that the gills are not borne on the genital operculum or abdominal plates, but occur dorsal to them as highly vascular areas of the body wall. The reasons for this conclusion are given below.

By analogy with living animals in many groups, we can say that blood vessels, muscular impressions, or chitinous thickenings, on the abdominal plates, would all tend to radiate from the point of attachment to the body, i.e. from the median anterior margin of the plate. But from observation of the specimen it can be seen that the origin of the tree-like markings appears to be towards the outer and posterior edges of the abdominal plate, and that the markings are directed slightly forwards.

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[1] This may yet be so, and the structures described above may be accessory or have some other function.

Secondly, it has already been pointed out in the description of the specimen that the fourth gill is impressed upon the fourth tergite and on a posterior segment of uncertain nature. But the first two gills are impressed upon abdominal plates or their modified equivalents (operculum). If then a gill may be impressed on a tergite or an abdominal plate the argument that it must be attached to the abdominal plate is weakened.

Both these considerations suggest that the gills are in the ventral body wall, and Holm's evidence is not against this. In fact this theory offers a better explanation of the thin integument which he figured in 1898, pl. v, figs. 11, 12, than to suppose that this is the upper skin of the abdominal plate peeled off (he himself admits that it may be the skin of the body wall). Holm's (1898) pl. x, fig. 9, mentioned above, gives confirmatory evidence.

Further, it is unlikely that a gill is borne at all on the opercular somite. *A priori*, analogies in many living animals suggest that on a segment thus specialized for reproduction, the respiratory apparatus would be atrophied. In *Limulus polyphemus* Latr., the operculum is much less specialized than in the Eurypterida, yet the respiratory apparatus is absent on this somite. The same applies to the scorpions (here the principle is extended to the second somite where tactile appendages occur), and also to the Pedipalpida, e.g. *Thelyphonus*, where there is a large operculum on the first segment, and the first stigmata appear on the second.

Hence it is probable that the first gill in Eurypterids, which is covered by the operculum, is in the body wall of the second mesosomatic somite,[1] and that it corresponds to the second tergite. It appears that appendages, i.e. an abdominal plate, are missing on this somite (correlated, no doubt, with the large size of the operculum). Had an abdominal plate been present, but concealed beneath the operculum, it would have been observed in distorted specimens, or in Holm's transparent preparations. Woodward believed that such a concealed plate did occur, but little importance can now be attached to his arguments, which were refuted by Laurie (1893, p. 513).

[1] On this point the writer is in agreement with Laurie.

Conclusion

It has long been noted that there are six tergites on the mesosoma, but only five pairs of appendages. The recognition of the operculum as a pair of modified appendages has meant the rejection of Hall's view (1859, p. 398, fig. 3) that it represented the " anchylosed 1st. and 2nd. segments of the body ". Recently Störmer has advanced a theory which appears to explain this discrepancy. He suggests that the first tergite of the Eurypterida is equivalent to the embryonic pre-genital segment of Xiphosura and Scorpionida, and that it is represented on the ventral side by the metastoma.

Most palaeontologists would agree in regarding the metastoma as homologous with the chilaria of the Xiphosura. But the arguments advanced in this paper suggest that the operculum is the equivalent of the first tergite, and that the second mesosomal segment is probably limbless though it bears a gill ; and further, we may suppose that the tergite to which the metastoma belongs is embryonic only, as in the Xiphosura and Scorpionida. On this view, the apparent homology of the six mesosmatic segments in the Xiphosura, Eurypterida, and Scorpionida would be confirmed (see below), whereas Störmer's theory denied this homology.

Segment.	*Eurypterida*	*Xiphosura.*	*Scorpionida.*
Pregenital	Metastoma	Chilaria	Embryonic
Mesosoma 1	Operculum	Operculum	Operculum
„ 2	Gills	Appendage + gills	Pectines
„ 3	Appendage + gills	„ „	Lung
„ 4	„ „	„ „	„
„ 5	„ „	„ „	„
„ 6	„ „	„ „	„

My thanks are due to Dr. O. M. B. Bulman for much help and advice in the preparation of this paper.

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EXPLANATION OF PLATE I.

Photographs of the right half of the mesosoma of a specimen of *Slimonia acuminata* (Salter) (Sedgwick Museum, Cambridge, No. A16237a), showing traces of five gills. × ⅓ approx.

FIG. 1.—Untouched.

FIG. 2.—Slightly retouched.

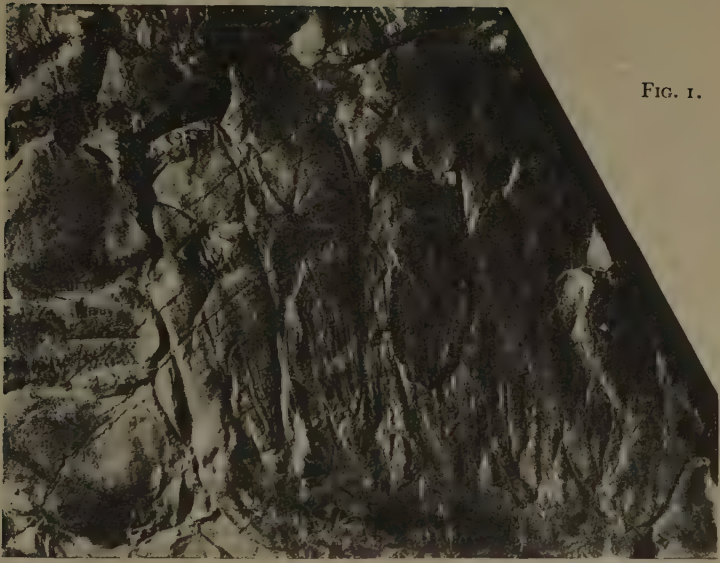

FIG. 1.

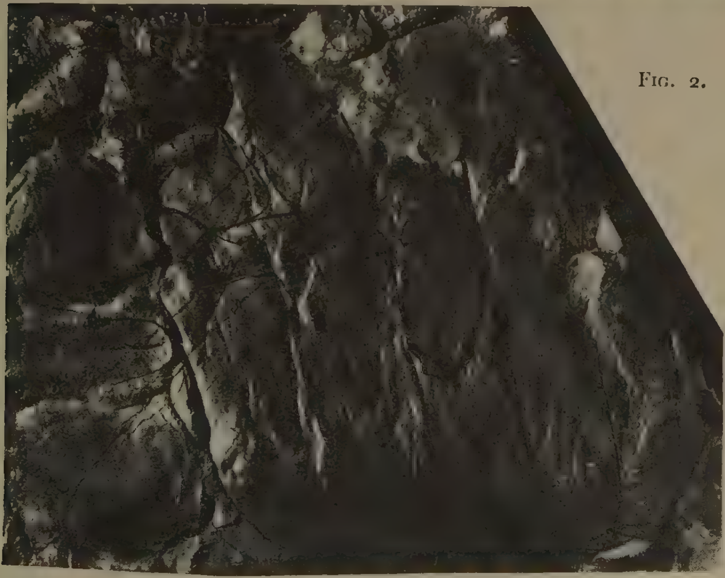

FIG. 2.

SLIMONIA ACUMINATA (Salter)

The Periods of Coal Formation represented in the British Coal Measures

By A. E. Trueman

As a result of recent work on the correlation of the Coal Measures in the various British coalfields it is now possible to determine the relative ages of the chief productive measures in the different areas. Some aspects of this work were summarized in 1933 but much further work has been done since that time, especially with reference to the Scottish coalfields (Weir and Leitch, 1936). The results of these investigations may be expected to throw considerable light on the physiography and other factors controlling the deposition of the Upper Carboniferous rocks, but in the present note attention is drawn only to the zonal distribution of the more important coals in various British coalfields.

Some features in the sequences in four coalfields, namely Central Scotland, Northumberland, Yorkshire, and South Wales are shown in the accompanying diagram (Text-fig. 1). The sections have been drawn on similar vertical scales, each section representing a described sequence within the coalfield; all coals with a thickness above 12 inches and of reasonably wide extent have been inserted but no other boundaries are marked. It will be clear that if other areas within the same coalfields had been chosen the details in some cases would have differed, but the general impression as to the time distribution of the coals would not have been modified to any significant extent.

The zonal boundaries inserted are those based on the study of the non-marine shells. While this basis of correlation has been adopted, however, it may be noted that it affords results which show no important difference from a correlation based upon the plants or the marine fossils. Indeed, the boundary between the lower and the upper parts of the Similis-Pulchra Zone corresponds with the horizon of the Mansfield Marine Band in Yorkshire, the Skipsey's Marine Band in Scotland, and the Cefn Coed Bed in South Wales. There are several lines of evidence which appear to indicate that these bands are contemporaneous and that they may represent a single widespread incursion of marine conditions in the British area (see Currie, 1937, 416). In constructing the diagram the base of the Similis-Pulchra Zone has been chosen as a datum plane. This corresponds with the Barnsley Coal in Yorkshire, the

Stanllyd or Nine-Foot Coal in South Wales, and with important seams in most other coalfields (Trueman, 1940, 39).

It is apparent at once that coal seams are most abundant at the same general horizons in all the coalfields represented in the diagram; these horizons are immediately above and below the datum line which has been chosen. Coal seams are seen to be most abundant in that part of the Lower Westphalian or Ammanian which falls within the Ovalis and Modiolaris Zones and the lower part of the Lower Similis-Pulchra Zone. If attention were paid to the actual thickness of the coal seams as well as to mere distribution in the sequence this concentration of the more important seams within the belt of strata defined by these zones would be still further emphasized.

A comparable distribution is shown by other coalfields. Thus there is general agreement in this respect amongst the Scottish coalfields (Weir and Leitch, 1936, 738). The sequence in Northumberland and Durham (Hopkins, 1939), shows many similarities to those of Scotland and Cumberland; Lancashire (Wright, 1929), North Staffordshire (Davies and Trueman, 1927), Notts. (Clift and Trueman, 1929), and North Wales (Wood, 1937), afford conclusions very similar in essential respects to those shown in the Yorkshire section. The coalfields of the South Midlands have not been included in the diagram but, while the Coal Measures there are generally thin, it is noteworthy that all the seams again occur between the Ovalis and the Lower Similis-Pulchra Zones. In those coalfields there is a concentration of seams to form the thick coals which commonly occur about the base of the Similis-Pulchra Zone (Trueman, 1940, 39). In the coalfields of Bristol and Somerset, where the sequence is very similar to that of South Wales, there is also a concentration of important seams within the same group of strata, although in this area as in South Wales it is familiar that important seams also occur at higher horizons extending above the Tenuis Zone (Moore and Trueman, 1937).[1] In other words, in all the coalfields of the North, of the Midlands, and in all the southern coalfields except the Forest of Dean (where these zones are unrepresented), and possibly Kent, the Ovalis, Modiolaris, and Lower Similis-Pulchra Zones are rich coal-bearing horizons; in several coalfields they are the only important productive horizons.

This widespread occurrence of thick coal seams at similar horizons over so great a part of Britain implies that the Coal

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[1] These higher strata may be referred to the zone of *Anthracomya prolifera*; they are probably equivalent to the lowest Stephanian of the continent.

Measure facies was extensively developed during the time represented by these zones. It suggests that there was remarkable uniformity of conditions over the greater part of Britain during those times, a deduction which appears to be further emphasized by the widespread occurrence of a marine horizon (the Mansfield Marine Band and its equivalents) after this important coal-forming period. It may be suggested that this uniform and wide distribution of coal formation is one of the most fundamental facts in the stratigraphy of the British coals, a view which is not in accord with the theory of deposition in limited basins (Trueman, 1933, 90).

Closer examination of the tables shows that the main episode of coal formation in Upper Carboniferous times commenced rather earlier in Scotland than in South Wales and also that it finished earlier in Scotland. On the other hand it may be noticed that coals are found in the Upper Carboniferous at much lower horizons in Yorkshire than the lowest occurring in the Upper Carboniferous of either Scotland or Wales.

These facts are of some interest in connection with the view (referred to in several text-books) that in Britain coal forests gradually spread southwards and that the most productive Coal Measures are progressively later in date from north to south. This conclusion has been based upon data rather different from those recorded here ; if the coals of the Lower Carboniferous are included it is obviously true that coal formation began earlier in Scotland and in Northumberland than in Yorkshire and in South Wales. It is also equally true that coal formation continued for much longer in South Wales than in any of the northern coalfields. These facts, however, do not warrant the conclusion that there was a general transgression of a " Coal Measure " facies. In the first place it must be emphasized that the coal formation which characterized part of Lower Carboniferous time in Scotland and Northumberland represented a separate episode which was quite unconnected with the later period of coal formation now represented in the Productive Coal Measures of the Upper Carboniferous of those areas. During the deposition of the Millstone Grit some thin coals were formed in many areas but these strata include few productive seams, and it is evident that the main period of coal formation which succeeded was not merely a southerly extension of this earlier (Lower Carboniferous) episode.

It must be remembered that these two episodes of coal formation in Scotland appeared to be separated by a smaller interval when Kidston put forward his original correlation of the Upper

Carboniferous rocks (1894, 1905); according to this view, the greater part of the Productive Coal Measures of Scotland were equivalent in age to the Lower Coal Measures of Yorkshire, and thus earlier than the main belt of coal-bearing rocks in that area. The interpretation of the floral sequence in South Wales and Somerset gave still further support to the suggestion that the productive Coal Measures became progressively younger towards the south. So far as the Scotland–Yorkshire correlation was concerned, however, Kidston later (1912) made modifications which implied a general equivalence of part of the Productive Coal Measures of Scotland and the Middle Coal Measures of Yorkshire; fuller knowledge of the floral succession has not merely confirmed this revision, but has made possible a zonal correlation which is in substantial agreement with that illustrated in Text-fig. 1 (Dix, 1934; Walton, Weir, and Leitch, 1938, 1349).[1]

It may be emphasized, therefore, that the most striking feature in the distribution of British Carboniferous coals is the widespread occurrence of important seams in practically all coalfields in the Ovalis and Modiolaris Zones and the lower part of the Similis-Pulchra Zone. Before this episode of extremely uniform and widespread coal formation, there had been more local episodes of coal formation in different northern areas, but there was not a gradual southward transgression of the "Coal Measure" facies; indeed, the Upper Carboniferous (Ammanian) episode may be said to have been initiated in the Yorkshire–Lancashire area, and to have extended thence both into Scotland and into Wales and Southern England.

Although the early episodes of coal formation do not appear to have been related to a regular and extensive transgression, there is no doubt that the time of cessation of coal formation became steadily later in the more southerly coalfields. Thus in much of Scotland there are no coals above Skipsey's Marine Band, but there are some seams in that position in South Ayrshire, in Northumberland, and in Lancashire, North Staffordshire, and Yorkshire; they extend to much higher horizons in South

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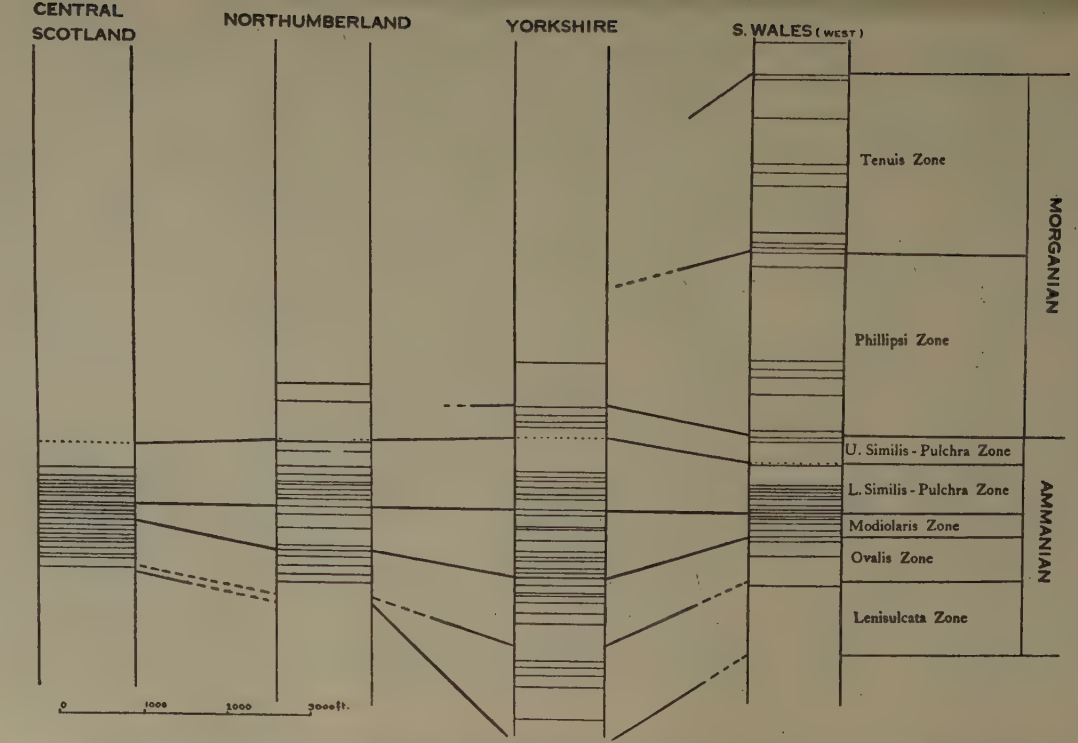
[1] The boundaries of floral zones are not always placed at the same horizons as boundaries of faunal zones; each such boundary presumably represents a change in either fauna or flora, and it need not be supposed that these changes in the two types of organisms always occurred simultaneously. It is not to be expected that future work will necessarily establish more frequent coincidences of this kind; indeed, the recognition of different horizons as zonal boundaries in the two cases may increase the possibility of detailed correlation when both types of fossils are studied. The boundaries do appear to coincide, however, at the horizon which marks the junction of Ammanian and Morganian.



TEXT-FIG. 1.—Sections of four coalfields to show the distribution of coals. The coals marked are those exceeding 12 inches in thickness and occurring over an extensive area. Fine dots mark the position of the Mansfield Marine Bed and its equivalents.

Wales and Bristol. This feature is no doubt linked with the progressively later onset of the conditions leading to the formation of red beds. There appears to have been some tendency for these conditions to advance southwards at the expense of the " Coal Measure " facies, but while they were widely established in all but the southern areas in Britain by an early stage in the Morganian, they did not become important in the southern areas during Morganian time. The relation of these changes to late Ammanian or early Morganian earth-movements is as yet obscure.

The author desires to thank his colleagues, Dr. J. Weir and Dr. D. Leitch, for helpful discussion of these problems.

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CORRESPONDENCE

SOME PROBLEMS OF GEOMORPHOLOGY AND CONTINENTAL RELATIONSHIPS IN BRITISH GUIANA

SIR,—The article by Mr. D. W. Bishopp, published in the July–August number of the *Geological Magazine*, contains some inaccurate and misleading statements about the geology of West Africa, which I feel should not pass without comment.

(1) *Kawere Formation.*—This Gold Coast formation, locally known as the "Kawere Group", is not of Upper Birrimian age, and it does not contain any volcanic agglomerates. It belongs to the Tarkwaian (not Tarquaian) System which is separated from the Upper Birrimian by a major unconformity.

(2) *Trend Lines.*—The average trend of the foliations and fold lines in the rocks of the Basement Complex is approximately north-east in the Gold Coast, and between north-west and north in Sierra Leone, and not north-north-east as stated by Mr. Bishopp.

(3) *Voltaian Escarpment.*—This escarpment is from 50 to 150 miles from the coast and not 300 km., and is not due to faulting.

(4) *Gorceixite.*—Mr. Bishopp states: "An important mineralogical resemblance is provided by the recent discovery (du Toit, 1937) in the Gold Coast of rolled specimens of gorceixite, hitherto known only in Brazil." His reference to "du Toit, 1937" is incorrect. This mineral was found by me near Tarkwa in 1936, and was determined and analysed by Messrs. E. H. Beard and W. H. Bennett of the Imperial Institute.[1] Since then I have found it in diamondiferous gravels in Sierra Leone and in the Birim Valley (Gold Coast).

(5) *Coast-line.*—According to Mr. Bishopp, "the downfaulted nature of the coast-line in the Gold Coast is accepted." Detailed study has shown, however, that the coast-line is of composite origin and has been determined principally by the strike of the rocks.[2] The younger sediments, Devonian, Carboniferous, and Cretaceous, all dip seawards towards the submarine trough which extends all the way from Cape Palmas (Liberia) to beyond the Gold Coast. This trough reaches a depth of 5,000–6,000 metres, and its slope on the coastal side is steeper than the slope of any other part of the Atlantic coast of Africa. The

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[1] *Annual Report of the Gold Coast Geological Survey*, 1937–38, p. 6.

[2] Junner, N. R., Geology of the Gold Coast and Western Togoland, *Bull.* 11. *Gold Coast Geological Survey*, 1940, p. 34.

trough has determined the east-west trend of this part of the African coast, and it appears to be a major tectonic feature. To the east it lines up with the Cretaceous-filled Benue depression in Nigeria, and to the west with the Amazon syncline, according to the restoration of the continents suggested by du Toit[1]; between them is the only break of any depth in the Central Atlantic submarine ridge. The fact that fossiliferous Devonian and Carboniferous rocks are not known anywhere else in this part of Africa, although they occur in the Amazon syncline, is significant. That the trough is still active seems likely from the numerous submarine earthquakes recorded from the equatorial zone between Brazil and the Gold Coast.

As long ago as 1868, Dr. Horton noted the great similarity in the geology of Brazil and the Gold Coast, and argued that: "These facts lead me to the belief that when the resources of the country (the Gold Coast) are much more developed, diamonds will be found not only in the eastern district, but also in the rivers and lagoons of Awoonah and Dahomey."[2] Since then many writers have stressed the similarities. Comparisons and correlations on lithological grounds of unfossiliferous sedimentary formations over great distances should, however, be accepted with reserve, and much less value should be attached to correlations of igneous rocks, such as granites, gabbros, and dolerites, unless their ages are known. In West Africa, for example, there are gabbros and dolerites of at least four different ages, and the Horizontal Sandstones, of which the Voltaian are part, probably range in age from Ordovician to Devonian or Carboniferous.

N. R. JUNNER.

BOX 25, PRESTEA,
GOLD COAST.
11th September, 1940.

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[1] A. L. du Toit, *Our Wandering Continents*, London, 1937, p. 108.
[2] J. A. B. Horton, *West African Countries and Peoples*, 1868.

REVIEW

Synopsis of the Mineral Resources of Scotland. By M. Macgregor and Others. Spec. Rep. Min. Res. Great Britain. Vol. xxxiii, *Mem. Geol. Survey*. pp. 59. H.M. Stationery Office, 1940. Price 1*s*.

The reading of this memoir gives rise to what may be to many people a somewhat startling reflection, namely that apart from the Carboniferous system of the central valley, the mineral resources of Scotland are but of trifling importance. There is, of course, abundance of building stones, road metal, gravels, sands, and clays, and so on, but of minerals in the strict sense remarkably few. The historic lead-zinc deposits of the Leadhills and Wanlockhead are little but a memory of the past ; the chromite of Unst is of some interest petrologically, but besides these there are hardly any ore-deposits. This draws attention to a curious fact, the strong contrast in this respect between the Highlands of Scotland and the corresponding rocks of Scandinavia, so rich in important mining areas. This point does not seem to have received the attention it deserves.

It follows, therefore, from these purely geological and mineralogical facts, that there is the strongest possible contrast between the industrial development of the central valley, with its rich stores of coal, oil-shale, and ironstones, and the rest of Scotland. This limited distribution of mineral wealth no doubt accounts for the fact, not often realized, that there are actually more people in Lancashire than in the whole of Scotland, and nearly as many in Yorkshire ; in both these counties as well as around Birmingham and in South Wales coal is the dominant factor in development and the same is clearly manifested in Scotland, where the only other concentrations of population, not depending on geological but on geographical reasons, are in the great ports of the east coast. In northern England water-power played a part in early development, and it remains to be seen what its future effect may be in Scotland.

ANNOUNCEMENT

Clough Memorial Research Fund

This fund was instituted in 1935 for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Cumberland, Durham, Westmorland, and Yorkshire. Under the terms of administration of the fund a sum of approximately £30 is available annually.

Applications for grants are invited for the period 1st April, 1941, to 31st March, 1942. These applications should state :—

1. The nature of the research to be undertaken.
2. The amount of grant desired.
3. The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavation of critical sections, etc.
4. Whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Research Fund Committee, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st March, 1941.

GEOLOGICAL MAGAZINE

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The Shoulders of Glacial Troughs

By C. A. COTTON

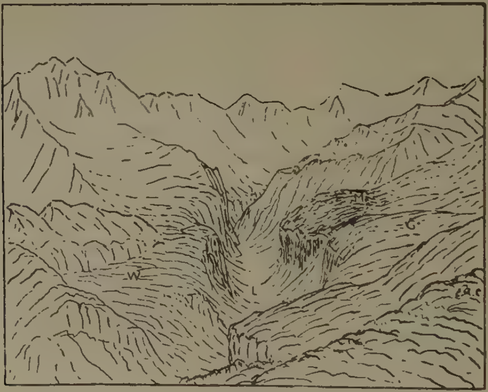
THE inner or immediate trough of a glaciated valley is now generally regarded as very closely related in origin to the glacier that last flowed in it, being equally a result of its erosive work whether vertically excavated or laterally opened by it. This is the *Trog* of Richter (1900), which he regarded as more or less exactly containing the glacier of the last glaciation during at least a great part of the period of trough-development, though signs of overflow at the height of the ice flood are found above the " shoulders " which bound the trough. Rarely does the trough comprise the whole valley: more commonly shoulders distinctly separate steep trough walls from gentler upper valley-side slopes. In addition to the inner trough-side shoulders, however, higher benches are in many cases unmistakably present, though they may be poorly defined and are always discontinuous, so that their correlation and restoration as a definite number of actual upper shoulders is by no means certain.

" ALPS "

Alpine benches in their most perfectly developed form are exemplified by the often cited " alps "—Wengernalp and Grütschalp—on either side of the near-vertical walled canyon of the Lauterbrunnen trough, in the Bernese Oberland, at heights of 2,000 feet and more above its floor and separated from it by nearly rectangular shoulders (Text-fig. 1).

Perhaps as sharp as these are the " shoulders " bordering a " trough " in Norway described by Suess (1888), who is credited with the first use of these terms in this sense. Suess, however, attributed only the bench above the shoulder, not the trough below it, to glacial erosion.

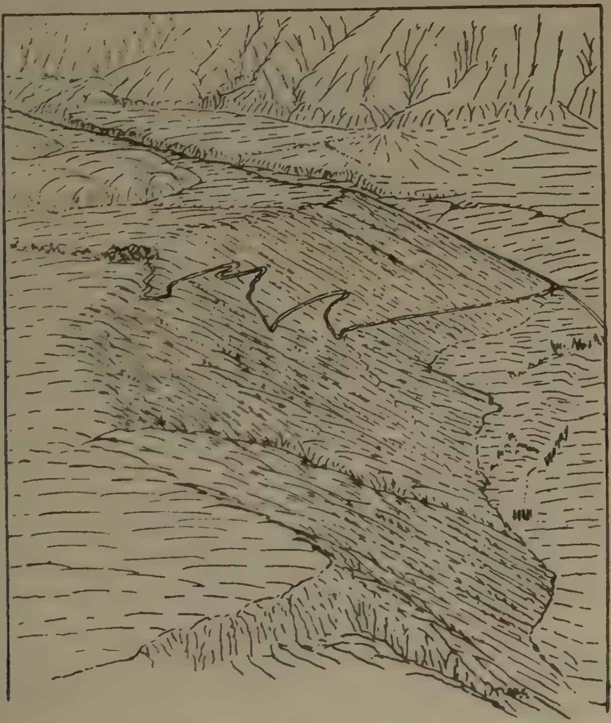
Benches such as these are now interpreted by most observers as remnants of troughs, or trough-floors, developed in penultimate and earlier glacial epochs, but others see in some of them valley forms made by rivers in interglacial epochs with or without much subsequent glacial modification (e.g. de Martonne, 1911). The hypothesis that the benched slopes are remnants of multi-cycle pre-glacial valleys seems to have found no supporters. A very remarkable single bench, however, in the glaciated Western Otago district of New Zealand, may have to be thus explained. This is the Crown Terrace (mentioned by Park, 1909), which, with a strong resemblance to river terraces in unglaciated districts, overhangs by 600 to 700 feet the floor of the Arrow Flat, an expanded part of the slightly glaciated Upper Kawarau valley (Text-fig. 2). The valley below and parts of the terrace itself (which consists of bedrock) are veneered with glacial deposits, and the glacier responsible for spreading these was about 1,000 feet thick, according to the conservative estimate of Ferrar (1928). This glacier seems to have had little movement, being near the eastern margin of the glaciated area and at a low level, and to have existed in a broad pre-glacial basin as a glacial " backwater " embayed at the side of a thick and more energetic tongue of ice which deepened the great valley of Lake Wakatipu. It seems that the Upper Kawarau glacier did no more than deposit some debris in the pre-glacial basin in which it rested and in places mould and smooth the outlines of the salient features of its floor. The Crown Terrace is a very prominent feature of this basin, bordering it for 6 miles. It is, however, unmatched on other flanks of the basin, and its counterparts there have been perhaps destroyed by more intense retrogressive glacial erosion.



TEXT-FIG. 1.—The Lauterbrunnen trough, with its shoulders. L, Lauterbrunnen ; M, Mürren ; W, Wengen ; G, Grütschalp.

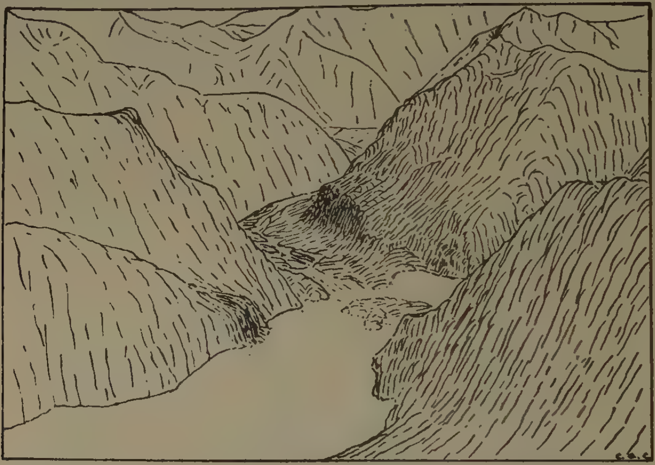
MULTIPLE SHOULDERS

To return to the multiple benched profiles of the European Alps, apart from general questions involving divergence of glacial theories, observers are by no means in complete agreement regarding the interpretation of individual shoulders. Though there can be no doubt of the existence of a stairlike arrangement of benches, many of the attempts that have been made to correlate the benches, so as to identify and restore strips of the valley-sides of a succession of epochs, must be regarded as tentative only, despite the confidence with which some of the results have been announced. Outside the Alps of Europe traces of benches at different levels are occasionally found, and a general explanation of the origin of such forms is desirable. Successive shoulders, with no systematic arrangement, so far as has yet been discovered, have been noted even on the steep walls of the fiords of South-Western New Zealand (Andrews,

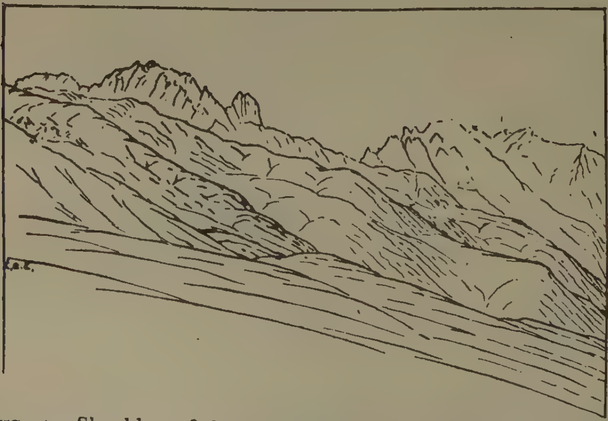


TEXT-FIG. 2.—The Crown Terrace (left) and Upper Kawarau Valley, New Zealand.

1906). The form of these in places suggests that they are remnants of trough-in-trough valleys (Text-fig. 3) nearly as forcibly as do the benches on the comparatively gentle slope of the Chamonix Valley figured by Garwood (1910) (see Text-fig. 4).



Text-fig. 3.—Shoulders of the Milford Sound trough, New Zealand.

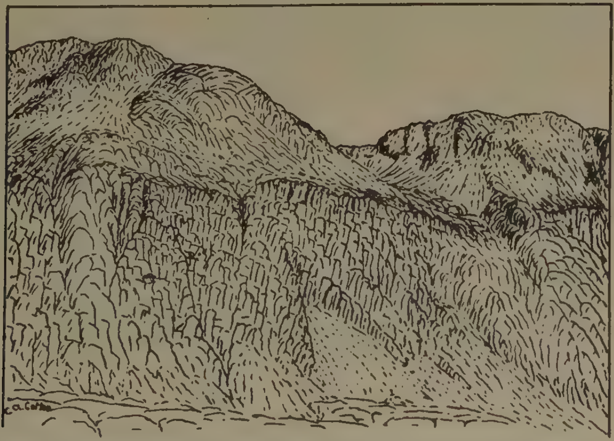


Text-fig. 4.—Shoulders of the Chamonix Valley. (From a photograph by E. J. Garwood.)

Non-Cyclic Benches

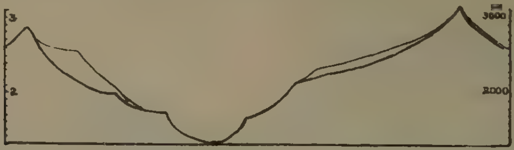
Pre-glacial Survivals.—Apart from shoulders of " cyclic " interglacial origin that may possibly be present, the sides of the valleys by way of which ice tongues have made their way out into the zone of ablation must exhibit a trough-side shoulder where the lower, oversteepened trough-side articulates with a non-glaciated upper valley-side slope, which may preserve pre-glacial landscape features with no glacial modification, though wasted away to some extent by normal erosion, of course, during the Glacial Period. The glaciers may have been thick and heavy enough in their lower courses, and retained sufficient motion, to overdeepen the axial parts of their valleys so as to convert them into basins which are now piedmont lakes, but, being confined to axial positions, have left upper slopes unaffected.

Pre-glacial features less perfectly preserved, perhaps somewhat ice-shorn during glacial overflow periods, and cut up to a varying extent by the development of high-perched cirques, may be present throughout the whole or greater part of a glaciated mountain range (Text-fig. 5).



TEXT-FIG. 5.—Shoulder above the eastern trough wall of the Hooker Glacier, New Zealand. A pre-glacial surface, somewhat ice-shorn, is present above the shoulder.

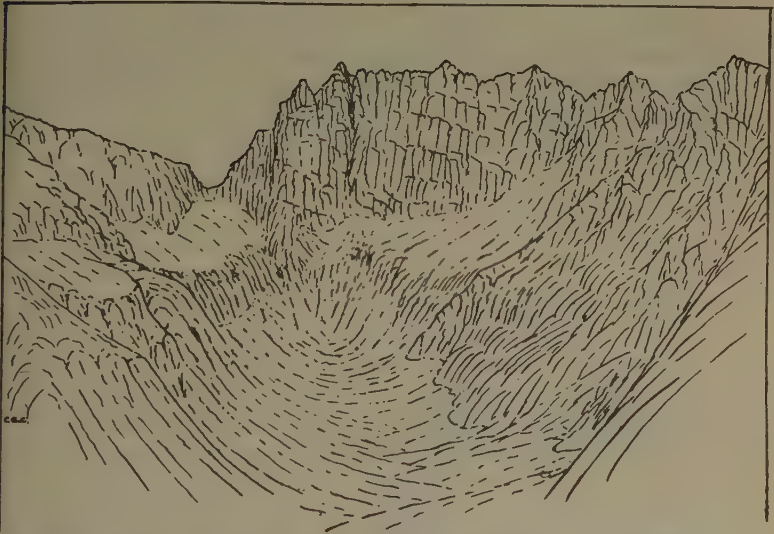
Cirque-floor Benches.—In the glacier-head zone of plentiful snowfall among high mountains another kind of bench and shoulder also of very evident origin may be present. Here vigorous development of cirques at about a common level (related in some way to the snow line) has produced continuous benches around trough-ends and for some distance down along some valley sides (Text-fig. 6), the result being a strongly marked angular shoulder between confluent cirque floors and the oversteepened trough-sides below. In Text-fig. 5, which shows the shoulder above the trough in which a remnant of the now shrunken Hooker Glacier still lingers, destruction of a somewhat ice-shorn pre-glacial landscape by development of cirques has just begun. Farther up the same valley, where this process has continued to greater maturity, it has more strongly emphasized the trough-side shoulder. In the central parts of the High Alps of Europe either steep trough walls extend to the mountain summits and arêtes, in which case there are no benches of any kind, as noted by Distel (1912), or there is a somewhat discontinuous bench of confluent cirque floors (Text-fig. 7). In such cases not only all pre-glacial forms, but also all possible remnants of landscapes developed either in interglacial epochs by normal erosion or in early glacial epochs by glacial erosion have been eliminated from the trough and associated forms by the attainment of landscape maturity in the last glaciation. In some regions of very deep glacial excavation also, such as



Text-fig. 6.—Cross profile of an Alpine valley (Stilluptal) showing inner trough and benches, the upper of which comprises cirque floors. (After Richter.)

the Yosemite canyon, in California, a similar absence of trough-side benches and shoulders (other than the high-perched edge of the upland plateau) may be noted, even far from the valley heads.

Structural Benches.—Another control, and one that is not always specifically mentioned in the discussion of glaciated forms, but of obvious importance in determining the positions and even existence of benches, is horizontal arrangement of beds or nappes. Conspicuous benches on outcrops of massive resistant sheets may have been developed by selective glacial erosion, though in some cases, no doubt, they are somewhat modified structural benches of normal origin dating from pre-glacial or interglacial times. Structural benches on horizontally bedded formations are typical features of the glaciated landscapes of the Canadian Rocky Mountains and of Spitsbergen; and in these regions of intense glaciation the benches cannot be attributed entirely to survival of pre-glacial forms. In Iceland also, notably on the fringes of Isafiord, and, as shown by Geikie (1898), in the Faroe Islands and North-West Scotland benches are structural. In the limestone Alps of the Bernese Oberland the most frequently cited of all glaciated benches, the "alps" bordering a part of the Lauterbrunnen trough (Text-fig. 1), owe their existence mainly to structure, being closely related to a limestone nappe, while above them tower the structurally benched slopes of the Jungfrau and adjacent peaks, which resembles those of the Canadian Selkirk Range on horizontally bedded strata. The unusually broad and flat "alps" at Lauterbrunnen are exceptional features of the Alpine landscape, finding their parallel only in some of the great fluvioglacial terraces, such as those of the Inn near Innsbruck. The very flat Lauterbrunnen benches, though at various heights at points not far apart (1,277 metres at Wengen and 1,642 metres at Mürren), have been taken by some observers for parts of a pre-glacial valley floor (e.g. Davis, 1900; Steinmann, 1910).

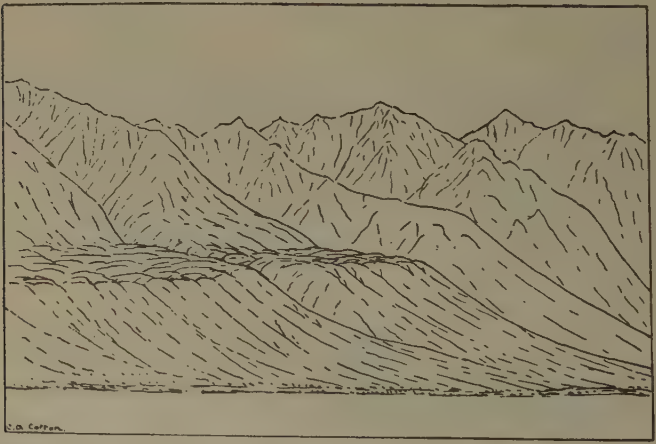


TEXT-FIG. ,7.—Trough-end and trough-side benches, in the Vallée des Etançons, resulting from development of confluent cirque floors. (Drawn from a photograph.)

The importance of structural terraces among valley-side bench forms has been emphasized by Blache (1938), who has called attention to the common error of assuming that some of these are instead remnants of valley floors of former landscapes such as may date from pre-glacial or interglacial cycles of normal erosion or from glacial epochs preceding the last glaciation. The fact that many benches are structural, though obvious, is discounted by some advocates of "cyclical" benches. "The hardness of a rock, it is said, permits the preservation of an erosion-level which would have been destroyed without the support of a solid foundation" (Blache, p. 17).

Distinct, however, from structurally controlled forms there are very numerous other valley-side benches conspicuous enough to be of some significance in the history of the erosion of the valleys—apart from their geographical importance, whatever their origin, in relation to the occupation and use by man of the Alpine valleys.

Morainic Benches.—An interpretation applicable to some stepped benches, but one which has a limited application and is easily tested, is that they are lateral moraine terraces successively stranded during the shrinkage of the last glaciers. Somewhat of this nature is one critical bench in the European Alps, which has been shown by Blanchard (1934) to have no significance as a remnant of a former valley floor. Lateral moraine terraces which are visible as prominent valley-side benches (Text-fig. 8) border that part of the Tasman Valley, in New Zealand, from which the Tasman glacier has withdrawn in post-glacial time. Three belts of stranded lateral moraines at levels about 1,000 feet apart lie on the catenary side slope of this great trough and decline in the down valley direction with the slope of the surface of the glacier at levels determined by successive halts in its withdrawal. The lowest lateral moraine plunges beneath the present



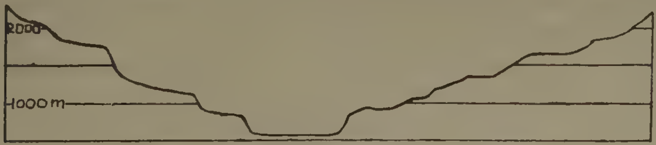
TEXT-FIG. 8.—Bench of stranded lateral moraine, at a height of 1,000 feet above Lake Pukaki, left by the shrinking Tasman Glacier, New Zealand; viewed from the terminal moraine at the foot of the lake (10 miles distant).

floor of the valley where this is formed by the delta at the head of the piedmont lake Pukaki.

Epiglacial Benches.—Other benches which are " non-cyclic ", or formed at quite accidental heights on trough-sides, are those termed " epiglacial " by Blache (1938). These include terraces cut by the lateral swinging of supraglacial water streams on large glaciers, and also actual " gutters " in similar positions developed where lateral melt-water streams have been superposed on valley sides : such have been described in the Cantal and Grésivaudan Valleys (Blache, 1914, 1931).

Cyclic Benches

As for the residue of multiple benches, such, for example, as those of the Aar Valley, near Meiringen (Text-fig. 9), which may have some " cyclic " significance, the problems presented by these have produced a harvest of theories as to their origin and meaning, which are of interest as working hypotheses. From the point of view of geographical geomorphology—the description of land forms—the benches are features of the landscape which present locally fascinating problems. Davis, however, dismisses them as follows (1912*a*) :—



Text-fig. 9.—Benches of the Aar Valley, near Meiringen. (After de Martonne.)

> " Close attention was . . . given in the Aar Valley to the occurrence of benches on the valley sides, from which successive epochs of glacial over-deepening have been inferred by some observers. Various opinions were held on this point by different pilgrims. For my own part, while it was easy to recognize one great trough of somewhat irregular or immature form, excavated beneath the higher mountain slopes, and while it was easy to see changes of slope in many profiles of the trough walls, the benches thus indicated were too ill-defined, too irregular, and too discontinuous to be accepted as proving the glacial excavation of a succession of troughs of smaller and smaller size to greater and greater depths."

It is noteworthy that the benches in the Aar Valley, specifically mentioned by Davis, are the most strongly marked of several bench-flights selected and figured by de Martonne (1935) as typical of such forms in the Alpine region (Text-fig. 9).

Apart from such interest as they may possess as landscape forms, multiple benched profiles have been seized upon by geologists (thinly disguised in some cases as geographers) as perhaps affording some clues to Quaternary history; but the somewhat doubtful nature of conclusions based on such evidence has been emphasized by Blache (1938) :—

> " L'histoire des glaciations, c'est dans les *dépots* glaciaires et fluvioglaciaires successifs qu'elle se trouve écrite le plus clairement. Le recours aux formes d'érosion ne procure pas une assurance comparable."

It has been recognized that the benches in question are fragmentary and irregular, but a number of patient workers in different Alpine valleys have attempted to arrange them in an orderly sequence. Their correlation from one irregular fragment to another is necessarily tentative and is liable to be influenced by the personal equation where it depends on the interpretation of views from distant vantage points and on the reading of topographic maps, the best of which are liable to be misleading as instruments of geomorphic research, and none of which in the nature of the case can be perfect. Some profiles reconstructed from such data, and all of them inevitably influenced to some extent by a prevailing theory, convey the impression of rather well-developed, almost terrace-like shoulders, generally four in number, almost continuously bordering some of the main Alpine valleys. Undoubtedly, however, the impression is illusory in some cases at least (Blache, 1938, pp. 14–16). Inspection of the photographs chosen, to quote but a single example, by de Martonne (1911, pls. 4, 5; 1935, pl. 39) from the Rhone Valley as a demonstration of the valley-side stairway of benches makes the unbiased reader suspect that the benches are in reality so irregular and discontinuous as to defy correlation with any approach to certainty.

Shorn of their quantitative interpretation, on which side one may well maintain an attitude of reserve, hypotheses proposed in explanation of the occurrence of valley-side benches in general must be of considerable value in the interpretation of actual individual bench remnants as land forms. These are with some show of reason regarded as indicators of valley-in-valley arrangement of landscape forms, and attempts are made to restore with their help the longitudinal profiles of valleys that have been successively destroyed prior to and during the excavation of the trough most recently occupied by a glacier in the valley. It is generally assumed as most probable that the benches are relics of older glacial troughs, but some restorations of longitudinal profiles which do not reveal traces of reversed slopes have been regarded as those of rivers, the presence of some reversed slopes having been made a criterion of restored glacial profiles by de Martonne (1912).

RELATION TO GLACIAL EPOCHS

The theory of progressive deepening and enlargement of valleys during four successive glacial epochs by glaciers and in the intervening epochs by rivers is rather generally adopted. To account for development of the troughs of which surviving shoulders seem to be remnants the simplest hypothesis is based on that of Richter (1900), who explained the inner trough as having been ploughed out during the last glaciation by a glacier contained within its limits, so that trough-in-trough forms may be tentatively accounted for as the results of excavation by the glaciers of successive epochs. Lack of regularity and continuity of the remnant benches, and in addition the presence above the shoulders of abundant traces of recent glaciation in the form of mammillated and polished rock surfaces, unweathered morainic deposits, and perched blocks, are among the kinds of evidence that have discredited this hypothesis in the opinion of some observers. It is agreed that most benches were submerged—but for how long there is no means of telling—beneath the ice of the last ice flood, and the older benches have no doubt been thus submerged over and over again. Hence the discontinuity of benches and their generally damaged condition and palimpsest characteristics are not surprising. The hypothesis of Richter, however, is not incompatible with the occurrence of occasional ice floods, the results of which would be some dulling of the edges of otherwise well defined troughs excavated or enlarged during epochs when glaciers were confined to the axial channels. According to Richter (1900, p. 53) typical troughs are developed by retrogressive (i.e. lateral) erosion—and where trough edges, or shoulders, are particularly sharp the glaciers which developed the trough features did not overflow their banks. The inner trough shoulder is sharpest where, as is a common case in some parts of the world, this trough is so fully developed that it takes up a great part of the valley to the exclusion of any possible remnants of most or all of the hypothetical earlier troughs.

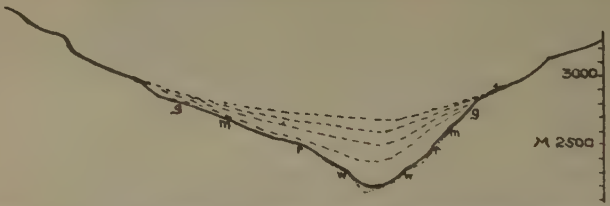
Recognition of well and widely preserved records in the form of benches surviving from three glaciations preceding the last, and perhaps also of forms developed in interglacial epochs, demands almost a return to the theory of the non-glacialists that ice is incapable of great erosion or that it produces no forms characteristic of its own work but merely adds, in Harker's words, the " final touches " to and shapes the " actual details " of a landscape. Even the initial forms of cirques are traced by Fels and by Ampferer back to Lower Miocene landscapes

(Flückiger, 1934, p. 48). Forms dating from early cycles are regarded as having been mysteriously preserved, however, during the removal of a very considerable thickness of rock material (Hess, 1938, p. 33), and the theory of their survival through successive glaciations has something in common with that surprising doctrine which assumes the survival (during lateral migration) of slope elements and breaks of slope without change for millions of years in normal landscapes.

HYPOTHESIS OF DOMINANT VERTICAL CORRASION

As is the case also with the longitudinal profiles, the transverse of glaciated valleys are differently explained by the advocates of overdeepening and by those who believe they see traces of more extensive lateral than vertical corrasion. These latter appeal to vertical corrasion by rivers in interglacial epochs for the deepening of valleys throughout the Glacial Period, of which all see evidence.

Vertical corrasion in conformity with Penck's (1900) theory of "overdeepening" (with accompanying "oversteepening" of trough walls) is relied on entirely by Hess (1938), who assumes the existence of a very broadly open V form in the pre-glacial valleys even at high altitudes in the heart of the Alps (Text-fig. 10), a form that suggests very advanced maturity of the whole landscape. In Hess's scheme little modification by normal processes is allowed for in interglacial epochs, but erosion in the four successive glacial epochs recognized by Penck and Brückner is called upon to do most of the work of conversion of the open valley form into the trough as it was finally left at the last melting of the ice—ice being credited with a capacity to erode at least ten times as rapidly as water. The work of



TEXT-FIG. 10.—A diagram of glacial trough development illustrating the theory of Hess. Heavy line, transverse profile of a high Alpine valley at the end of the last glaciation. Broken lines, earlier glacial profiles, and pre-glacial profile. Shoulders preserving relics of the troughs of successive glaciations are shown at *g*, *m*, *r*, *w*. (After profiles by Hess.)

ice is regarded by Hess as being entirely vertical and greatest where the ice is thickest, as indeed is the opinion expressed also by Davis (1912*b*, p. 410). The erosive intensity (according to Hess's formula) varies as the square of the depth, so that the axis of the valley is most deepened. (It is of interest to compare this argument with that of de Martonne (1924), who, though he estimates that erosive intensity varies as the cube of the depth, comes to a very different conclusion regarding the effect of vertical corrasion on the axial depth of the valley.)

In the case of the typical valley figured by Hess (Text-fig. 10) vertical corrasion is estimated to have gone on at an average rate of 1 mm. per year throughout the width of the glacier-eroded valley, but increasing to 5 mm. per year at the valley axis. The excavation of the valley is assumed to have taken 600,000 years, but during a considerable part of this it was drained by rivers in interglacial epochs, and to these very little valley deepening is attributed.

HYPOTHESIS OF DOMINANT LATERAL CORRASION

In contrast with the doctrine of overdeepening and oversteepening by vertical corrasion, a theory of dominantly horizontal glacial corrasion is also in favour, having been adopted by Garwood (1910), de Martonne (1911, 1924), Sölch (1935), and others, and first stated explicitly by Richter (1900, p. 50). According to this lateral corrasion theory valleys are deepened mainly during interglacial epochs, when narrow trenches are cut in their floors by rivers revived (according to de Martonne) by continuous post-Tertiary uplift in the Alpine region. Garwood (1902, 1910) has also suggested uplift in the last interglacial epoch. Alternation of vertical corrasion effected by rivers with glacial corrasion which is mainly lateral results ideally in a trough-in-trough valley form, in which the successively opened troughs are, however, of diminishing width and capacity. At the height of each ice flood in the later epochs, therefore, the ice may be expected widely to overflow upper benches, and possibly the fragmentation and progressive destruction of these may thus be satisfactorily accounted for.

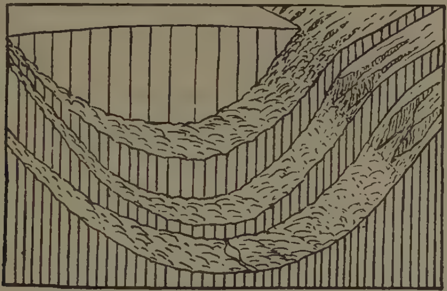
According, however, to the formula given by de Martonne (1924, p. 136) for the friction between the glacier and its bed, relied on by him as determining the measure of vertical corrasion, this varies as the cube of the thickness of the ice, and the enlargement of V-shaped valleys into trough forms apparently by a concentration of vertical corrasion on their flanks seems inconsistent with the formula. De Martonne relies on this formula for the explanation of the development of the longitudinal glacial floor profile; but explains the cross profile of the trough as solely due to the efforts of the ice stream to cut for itself a channel bounded below by an arc of a circle—the "hemi-cylindrical groove" of Richter (1900, p. 50).

Though it is termed *sapement* by de Martonne, and referred to as retrogressive erosion by Richter and Sölch, the kind of erosion which is relied on by these authors for transformation of valley profiles from "V" to "U" form is purely vertical corrasion by the ice stream, such as may be regarded as analogous with the action of a straight stream of water deepening a gorge. Only occasionally references have been made to the possibility of lateral corrasion taking place that is in any way analogous with the familiar undercutting by water streams on the outer sides of curves—e.g. by Andrews (1906) and by von Engeln (1938); and very rarely has true lateral sapping by freeze-and-thaw along the sides of glaciers been considered as a possibility. This is a process that may perhaps result in valley-side steepening after the manner of head-wall recession in cirques. Gilbert has found trough sides thus steepened by sapping near valley-heads in the Californian High Sierra (1904, p. 582), and Taylor (1914, 1922) has developed in detail an hypothesis to account for the shaping by frost-work of broad catenary trough forms. This hypothesis has, strangely, been entirely overlooked by Alpine investigators.

POST-GLACIAL MODIFICATION OF TROUGH-SIDE SHOULDERS

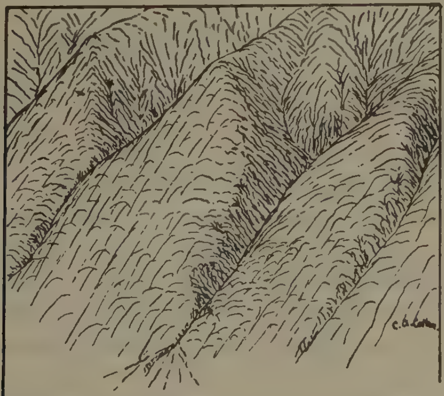
When the rapidity with which some trough-sides have been trenched by normal ravines in the short post-glacial interval is considered, it does not seem remarkable that the shoulders of the troughs of earlier glaciations have been much dissected and in great part obliterated in long interglacial epochs. Even before their submergence under widespreading later ice floods the shoulders left by early glaciations must already have been reduced to a fragmentary condition by dissection.

Post-glacial dissection of trough-side slopes by ravines has accompanied the gradual shrinkage of glaciers since the last glaciation, and is in many places already far advanced—notably in the greywacke ranges of the eastern side of the New Zealand Alps, in Canterbury (Speight, 1923). Dissection has, indeed, considerably changed the appearance of the side walls of valleys in which glaciers still linger, and it is reasonable to regard a considerable part of all such ravining as having been done during the glacial epoch. It may perhaps have followed on the abandonment of upper walls of a trough to normal erosion as a glacier has entrenched itself more and more deeply in an abraded groove of progressive overdeepening (Davis, 1912*b*, p. 412), as indicated in Text-fig. 11.



TEXT-FIG. 11.—A glacier progressively deepens its trough and abandons the upper side walls to normal erosion. (After a diagram by Davis, redrawn.)

An effect of superglacial trough-side erosion has been to produce the Y valleys of some present-day landscapes. (W. M. Davis so described these forms, orally, when in their presence at Lake Wakatipu, New Zealand, in 1914. I have no doubt there is a reference to Y valleys somewhere in his writings.) They take this Y form when open V-shaped valleys of superglacial origin (or possibly in some cases pre-glacial) on the upper part of the side of a catenary trough are continued downward in the stem of the Y by narrower post-glacial ravines. Fine examples of such valleys are present along both sides of the broad trough of Lake Wakatipu (Text-fig. 12).



TEXT-FIG. 12.—Y valleys on the eastern side of the catenary trough of Lake Wakatipu (opposite Pigeon Island), New Zealand.

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The Alteration of Detrital Minerals in the Mesozoic Rocks of Yorkshire

By Frank Smithson, Birkbeck College, University of London

Introduction

Dr. R. H. Rastall (1932) has described the petrography of the Middle Jurassic sandstones of Eskdale and shown that they possess a remarkably restricted suite of detrital minerals, having for example no garnet or staurolite, but containing much anatase and brookite, both apparently of authigenic origin. The present writer (1934) showed that in other parts of North-East Yorkshire beds of the same age contain relatively rich heavy mineral assemblages. After a more detailed survey the writer was able to show (1939 *c*, Text-fig. 2) that the peculiar restricted assemblage was confined to a belt or elongated oval area—which can be roughly defined as occupying the north-west and north-east quarters of Sheet 43 (Geol. Survey " one-inch " map) and the north-east quarter of Sheet 44—and that as one passed outward from this area one met with increasingly richer assemblages at all horizons in the Middle Jurassic.[1] This result, as well as the results of mapping certain other characteristics of the assemblage, led the writer to suggest that this belt, which coincides closely with the Cleveland axis, is a belt along which active decomposition and alteration has occurred in these deposits after they were laid down.

It is proposed here to discuss these changes in greater detail and to consider to what extent they may have affected the neighbouring Upper Jurassic and Triassic rocks. The data relating to the Upper Jurassic and Trias were collected during the preparation of two earlier papers. For that dealing with the Triassic sandstones (1931) forty-six samples were examined; for that dealing with the Upper Jurassic (1934) forty-six samples from the Kellaways Rock and twenty-nine from the more sandy beds of the Corallian were examined. These surveys were much less detailed than that of the Middle Jurassic (667 samples), but as the records used were made before the writer had arrived at his present views there are certain advantages in not attempting to add to them.

It may be stated at once that all these rocks yield relatively rich assemblages in their more southerly outcrops, but near the latitude of the Cleveland axis the number of detrital species recorded per sample is distinctly smaller. It is, however, more instructive to consider each mineral separately.

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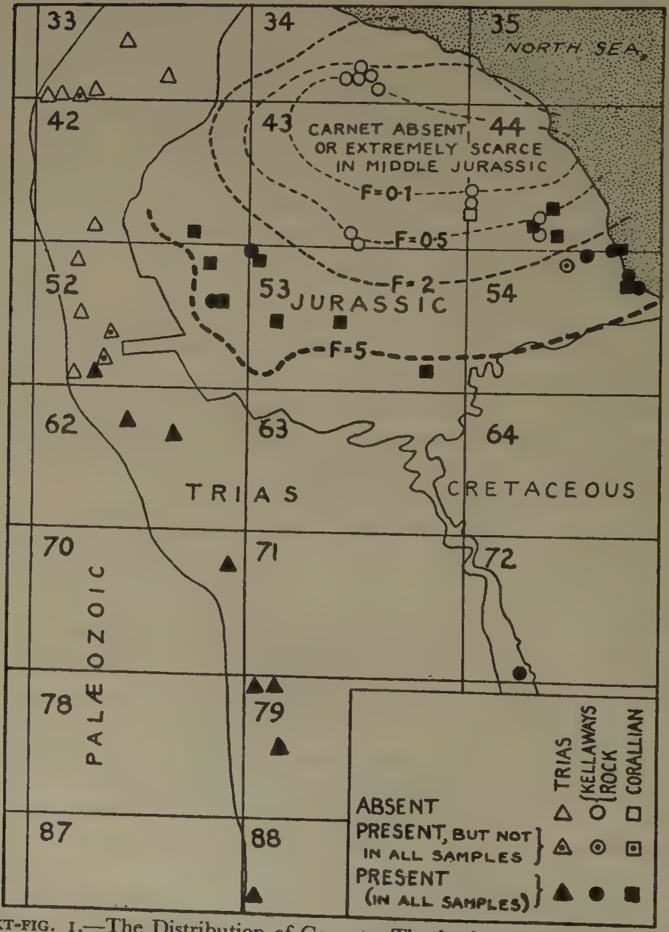
[1] The term " Middle Jurassic " in the present paper will be employed to describe all the strata lying above the Dogger and below the Cornbrash; that is to say, not quite the whole of the Middle Jurassic or Lower Oolites as usually defined.

GARNET

In Text-fig. 1 the occurrence of garnet in the Upper Jurassic and Trias is shown, superimposed upon a frequency map [1] for



TEXT-FIG. 1.—The Distribution of Garnet. The broken lines, F = 0·1, etc., indicate the frequency of the mineral in the Middle Jurassic. The boundaries of the "1-inch" maps of the Geological Survey and their respective sheet numbers are indicated. Scale: 1 inch = 16 miles.

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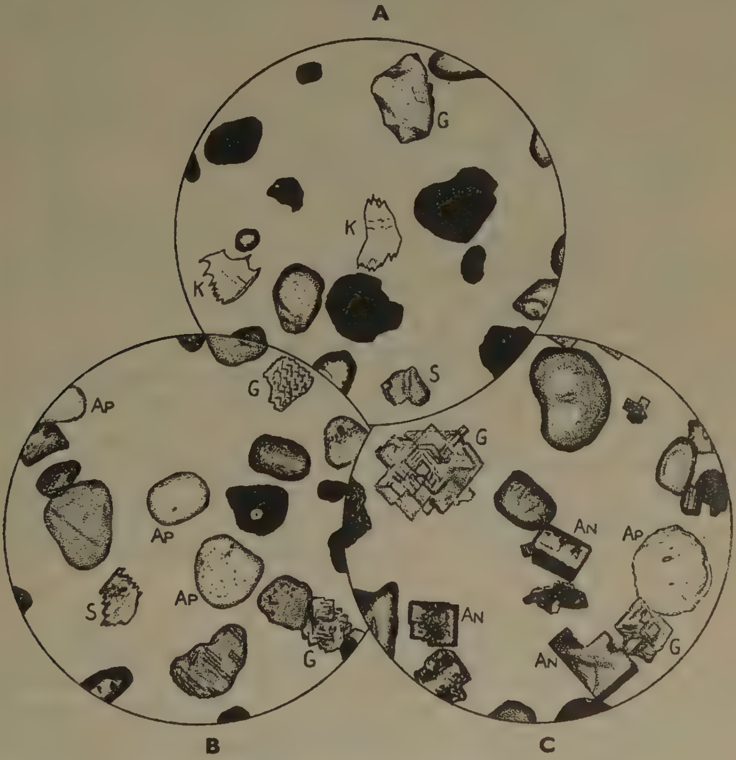
[1] This portion of the map is reproduced from the paper referred to above (1939 *c*) where the method of construction is explained.

garnet in the Middle Jurassic. In the Corallian, garnet is absent at only one locality (Saltersgate), which lies near the area where garnet has a mean frequency, in the Middle Jurassic, of less than 0·1. In the Kellaways Rock garnet is absent at all localities within or near the 0·5 frequency line for the Middle Jurassic. Thus, although the outcrops of Upper Jurassic rocks are somewhat inadequate near the critical area of Sheet 43, it is clear that in these deposits garnet is absent in those areas where it is absent or scarce in the Middle Jurassic.



Text-fig. 2.—Heavy Mineral Assemblages. Magnification: × 65.
A. From Kellaways Rock (sand), South Cave.
B. From Trias (yellow sandstone), Great Ouseburn.
C. From Lower Estuarine Series (sandstone), Saltwick Bay.
Key to lettering of grains: An = Anatase; Ap = Apatite
G = Garnet; K = Kyanite; S = Staurolite.

In the Trias, from the most northern outcrops to the middle of Sheet 52, garnet is absent at all localities except Neasham, where it is extremely scarce. Everywhere south of Sheet 52 garnet is present. Thus near the latitude of Sheet 42 (lying to the west of Sheet 43) the Trias apparently contains no garnet.

Garnet showing signs of corrosion occurs rather widely both in the Triassic and Jurassic deposits, but appears to be particularly characteristic of the areas bordering the region where the mineral is absent. Professor P. G. H. Boswell (1934, p. 44), discussing the stability of garnet, states, giving references to the literature :—

> " D. D. Condit, T. O. Bosworth, and H. H. Thomas seem to have been forced to the conclusion that the sporadic and peculiar occurrences of garnet in sediments were due to changes in drainage-direction, but other difficulties created by this explanation remained.
>
> " A large number of investigators noted the peculiar etching of garnets, chiefly along the planes of the rhomb-dodecahedron, and many (P. G. H. Boswell, A. Gilligan, H. H. Thomas, W. Mackie, and others) regarded it as evidence of solution of the mineral. Whether or not this well-known etching is to be regarded as an early stage of its disappearance, it is significant that M. N. Bramlette was able to imitate the natural etching . . . by subjecting the mineral to treatment with hydrofluoric acid."

The distribution and appearance of the etched or corroded grains in the Mesozoic rocks of Yorkshire is in keeping with the view that the etching is an authigenic feature. The first stage appears to be the development of a slightly mammillated surface, then of a minute rhomb-pattern, and as corrosion proceeds the grain becomes etched to form a " skeleton crystal " with a rhombic dodecahedral structure (Text-fig. 2 C) ; while the final stage seems to be the total disappearance of the mineral.

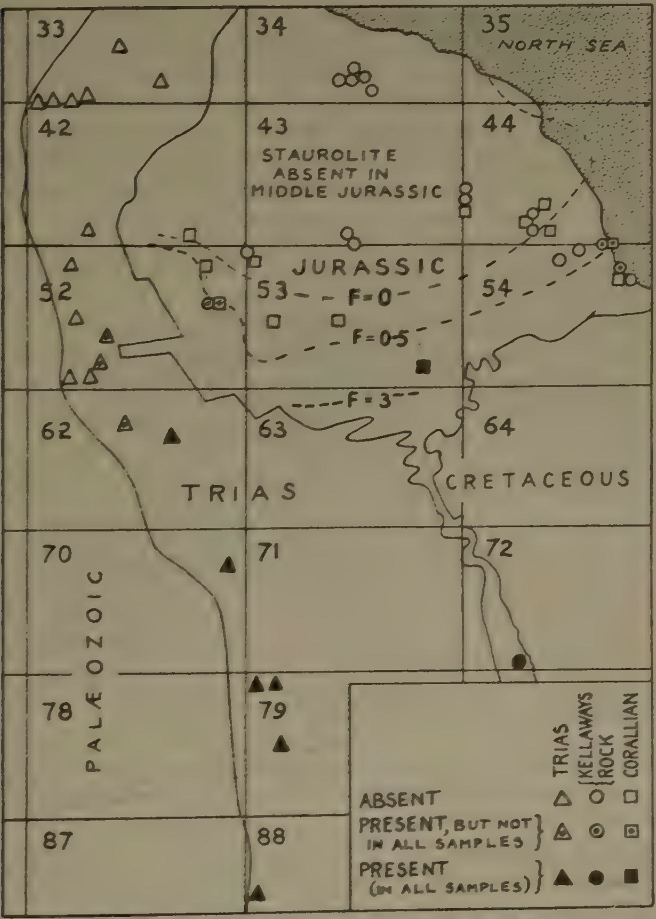
STAUROLITE

In the Jurassic rocks staurolite occurs in small amounts wherever garnet is fairly common, but there is no evidence that it extended to the north or north-west where garnet is present in small amounts in the Middle Jurassic (Text-fig. 3). In the Trias the distribution of staurolite agrees fairly closely with that of garnet.

Some of the Triassic residues contain rounded grains of staurolite whilst in the Jurassic many sub-angular and occasional euhedral grains are observed. Much of the staurolite, however, shows etching somewhat similar to that of garnet. The etched grains have a ragged outline, the direction of the sharper spikes being usually along the *c* axis, as shown by the pleochroism.

MONAZITE

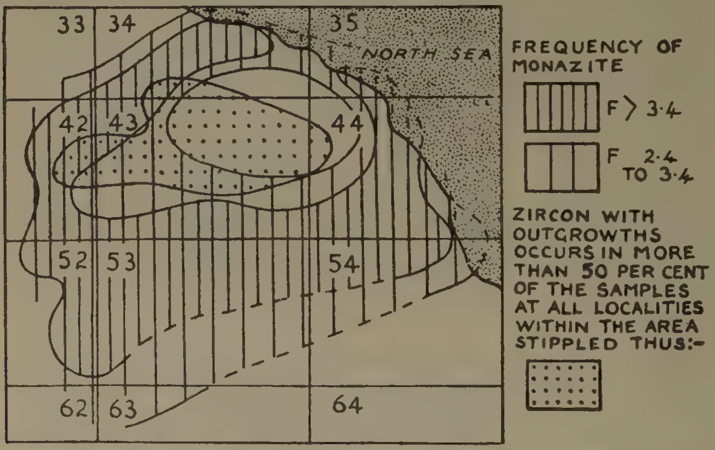
Monazite is easily overlooked when searching a slide. When once a grain is suspected it can be readily tested by its absorption spectrum, provided the grain is not extremely small ; but pale grains may look so much like zircon that the observer may neglect to apply the necessary test. Thus a statement of the frequency of this mineral in any slide or even the accuracy of a decision as to whether it is present or absent is determined to some extent by chance. Where the number of samples examined is small this may be a serious matter, but with an increasing number of samples a fairly true statement is more likely to be obtained. For this reason details of the distribution of monazite will be given only for the Middle Jurassic. For the Trias it is



Text-fig. 3.—The Distribution of Staurolite. The broken lines, F = O, etc., indicate the frequency of the mineral in the Middle Jurassic. Scale: 1 inch = 16 miles.

sufficient to state that no monazite was proved in Sheets 33 or 42; whilst farther south the mineral was proved in most samples.

When the mean frequency values of monazite in the Middle Jurassic for each district were recorded on the map their distribution at first appeared to be somewhat erratic. A closer inspection showed that the lowest frequency values for this mineral occurred (i) in the region where the suite is most restricted, and (ii) in the region where the suite is richest. Thus the simplest interpretation which could be adopted showed an oval area of low frequency in the north-east corner of Sheet 43, surrounded by a ring of higher frequency, outside of which—where the outcrops extend far enough—there are areas of low frequency. This distribution is shown most clearly in the map for the Lower and Middle Estuarine Series (Text-fig. 4).


33
34
35
NORTH SEA
42
43
44
52
53
54
62
63
64
FREQUENCY OF MONAZITE
F > 3·4
F 2·4 TO 3·4
ZIRCON WITH OUTGROWTHS OCCURS IN MORE THAN 50 PER CENT OF THE SAMPLES AT ALL LOCALITIES WITHIN THE AREA STIPPLED THUS:-

Text-fig. 4.—The Distribution of Monazite and Zircon with Outgrowths in the Lower and Middle Estuarine Series (combined). Scale: 1 inch = 16 miles.

It is not difficult to see how such a distribution could arise. Assume that at the time of deposition monazite was scarce but evenly distributed. As solvent action began to remove garnet and other minerals less stable than monazite, the percentage of monazite in the heavy assemblage would increase, thus tending to give monazite a distribution exactly the reverse of that of garnet. But if finally at the very centre of the region solvent action became so intense as to remove much of the monazite and produce a frequency depression for that mineral, then a distribution such as the one depicted in Text-fig. 4 would result.

If this explanation is true we should expect to find partially dissolved grains of monazite; yet, although occasionally the surface of monazite shows a slight pitting or a suggestion of an etching pattern (no acid having been employed in laboratory treatment), there is no such widespread or convincing evidence as in the case of garnet or staurolite. We know, however, that monazite even in recent deposits is often coated with films of a reddish brown decomposition product without the development of any definite pattern. In the Jurassic residues one frequently finds grains with a brown incrustation, cracking and partly peeling away, which may be of a similar nature.

APATITE

In all the formations studied apatite is frequently found in a quite uncorroded condition in residues where garnet is highly corroded (Text-fig. 2), and in the Trias it occurs as abundantly as zircon in the region where we have suggested that garnet has been destroyed. Corroded apatite has been observed both in the Trias (Smithson, 1931, p. 130, and Plate 5), and in the Jurassic rocks, its distribution being apparently erratic and controlled by factors quite different from those which produced the corrosion of garnet. It is probable that the corrosion of apatite in many cases is caused by recent weathering. The corroded grains usually show ragged terminations; that is to say, they are terminated by spikes parallel to the *c* axis, as though solution had occurred along prismatic cleavages.

In the Middle Jurassic, the area from which apatite is completely absent is in the form of a " tongue " entering the region from the north-north-west (Smithson, 1939 *c*, Text-fig. 5), and should be attributed to the influx of apatite-free detritus from that direction rather than to decomposition after deposition.

Secondary growths of apatite upon rounded grains of apatite have been observed in one sample of Lower Estuarine sandstone at Beck Hole (in the north-east quarter of Sheet 43). Secondary apatite occurs in the Trias in contact with the Cleveland dyke (Smithson, 1931, p. 134, and Plate 5), but the occurrence at Beck Hole is more than a mile away from the dyke and must be due to some other cause.

OTHER DETRITAL MINERALS

Among the other heavy detrital minerals the following appear to have withstood regional alteration—zircon, rutile, tourmaline,[1] ceylonite and chloritoid, as well as the detrital grains of anatase and brookite.

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[1] Within a few inches of the Cleveland dyke where it passes through the Middle Jurassic sandstones tourmaline has been removed, to be redeposited as secondary growths slightly farther away. In the same rock the etching of ceylonite has been observed.

Kyanite has not been found in the Trias, but in the Jurassic rocks it occurs at a few localities (e.g. in Sheet 72 around South Cave, where it has been observed in the Middle Lias, the Cave Oolite, the Estuarine Sands, and in the Kellaways Rock). The grains commonly exhibit ragged terminations or still more corroded forms (Text-fig. 2 A). One may surmise that the distribution of kyanite was formerly wider than at present and that it has become more restricted as a result of decomposition; but there is at present insufficient evidence to decide to what extent this may be true.

Magnetite is well known to be liable to alteration, e.g. to limonite. Its complete absence from many of the residues may be due to such a change. Its distribution has been studied in detail only in the Middle Jurassic. The mineral is scarce in the eastern half of Sheet 43 and in Sheet 44; and although along the western escarpments it is usually fairly common there are isolated localities even there where it is scarce.

OUTGROWTHS ON ZIRCON

A map showing the distribution of zircon with outgrowths in the Middle Jurassic rocks has already been published (Smithson, 1939 *c*, Text-fig. 8), and it has been pointed out that the distribution is antipathetic to that of garnet and to that of richness of the suite.

Dr. A. Brammall in a personal communication expresses his suspicion that the outgrowths may be a rare earth mineral isomorphous with zircon and suggests that certain X-ray and spectroscopic tests should be made with a view to testing this possibility. In this connection it is of interest to observe that the geographical distribution shown in Text-fig. 4 suggests an antipathetic relationship between monazite and zircon with outgrowths in the centre of the region, that is to say the outgrowths have developed most frequently in the area where the rare earth mineral, monazite, appears to have suffered decomposition. This must not, of course, be taken as proof of any causal connection between the two phenomena, but it offers some encouragement for examining the explanation which Dr. Brammall has tentatively proposed. On the other hand, if the outgrowths are considered to consist of zircon it seems necessary to assume that some zirconium-bearing mineral has suffered decomposition and that zircon has crystallized at a temperature much lower than that at which it is normally formed.

The outgrowths have not been observed in the Upper Jurassic rocks; in the Trias they occur only at Coatham Stob, north of the Tees, where the sandstone is in contact with the Cleveland dyke.

THE TITANIUM DIOXIDE MINERALS

In the Trias authigenic plates of anatase are observed but no authigenic brookite has been found; in the Upper Jurassic rocks authigenic anatase, both tabular and pyramidal in habit, occurs as well as authigenic brookite. But in these divisions the amount of data accumulated is insufficient to afford an explanation of the distribution or mode of formation of these minerals.

For the Middle Jurassic rocks much more evidence is available. Here both anatase and brookite occur as authigenic crystals, frequently in great abundance. As a detrital mineral anatase is fairly common at some localities and horizons; detrital brookite is extremely scarce; whilst detrital rutile is always present, usually in considerable quantity. In earlier papers the writer (1939 *a*, *b*, and *c*) has arrived at certain conclusions relating to these minerals in the Middle Jurassic. These conclusions will be summarized here without giving details of the evidence:—

(1) Tabular authigenic anatase tends to be associated with zircon larger than itself, tabular detrital anatase with zircon smaller than itself (1939 *b*, 359). If the rounding of the supposed detrital grains were due to the corrosion of authigenic anatase this relationship should not hold good.

(2) Authigenic anatase and authigenic brookite are not derived from rutile, which behaves throughout as a stable detrital mineral (1939 *a*, 306); but they may have been derived from the alteration of ilmenite and leucoxene [1] (1939 *a*, 308).

(3) Where TiO_2 is available for anatase or brookite the two do not share it equally, but all or most of the material tends to go into one form and little or none into the other (1939 *a*, 309).

(4) On the margins of the area of deposition where the sediments are coarse the authigenic anatase tends to be tabular, whilst along the Cleveland axis, especially towards its eastern end, pyramid faces are more strongly developed (1939 *c*, Text-fig. 9). The distribution of the tabular habit and its relationship to the coarseness of the sediment is brought out more clearly by superimposing a zircon-size map upon a frequency map for tabular anatase, as in Text-fig. 5. It may be added that the tabular variety tends to be yellow, whilst the pyramidal variety tends to be blue.

(5) Size-frequency studies show that the tabular form of detrital anatase as a whole is about the same size as the tabular authigenic anatase (1939 *b*, 355).

(6) Leucoxene is more abundant than ilmenite towards the north and north-west and in the marginal regions, that is to say in regions where

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[1] By means of X-ray analysis, S. A. Tyler and R. W. Marsden (*Journ. Sed. Pet.*, 1938, viii, 55), have shown some samples of leucoxene to consist of cryptocrystalline rutile and, in one case, of cryptocrystalline anatase. The nature of the Yorkshire Jurassic leucoxene is not known.

authigenic anatase is common. Towards the south, where authigenic anatase and authigenic brookite are absent, ilmenite is the dominant titanium mineral (1939 *c*, Text-fig. 6).

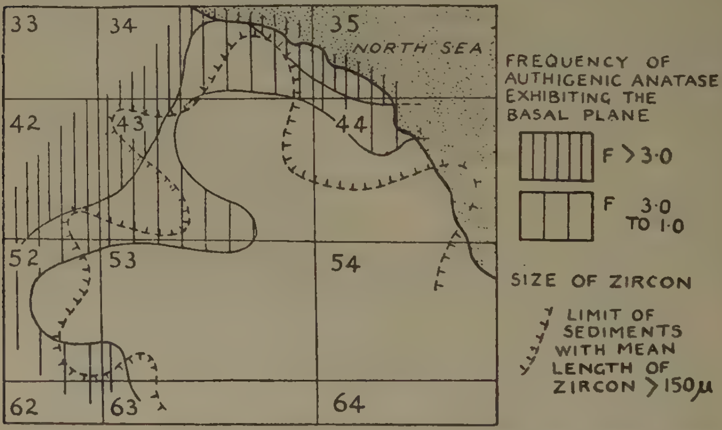
Some further facts not hitherto published must now be added as bearing on the problem in hand :—

(7) Detrital plates of anatase are commonest in the region (central and south-east) where authigenic plates are scarce or absent.

(8) Detrital plates are largest in the places bordering the region from which they are absent. They are large in and near the marginal regions where authigenic plates are common.

(9) Detrital plates vary in abundance throughout the vertical column, being much more common in the Ellerbeck Bed (marine) and in the Upper Estuarine Series than at other horizons.

(10) Authigenic brookite attains its greatest abundance along the Cleveland axis, in an area coinciding roughly with that in which blue pyramidal anatase occurs (Text-fig. 6).


33
34
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NORTH SEA
42
43
44
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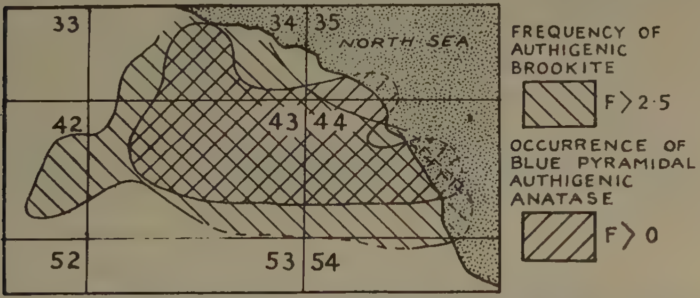
53
54
62
63
64
FREQUENCY OF AUTHIGENIC ANATASE EXHIBITING THE BASAL PLANE
F > 3·0
F 3·0 TO 1·0
SIZE OF ZIRCON
LIMIT OF SEDIMENTS WITH MEAN LENGTH OF ZIRCON > 150μ

Text-fig. 5.—The Distribution of Authigenic Anatase and of large grains of Zircon in the Lower and Middle Estuarine Series (combined). The anatase included here covers both the distinctly tabular types and those in which both the basal plane and the pyramid are developed, but excludes those in which only pyramid faces are present. Scale: 1 inch = 16 miles.

It is now possible to offer an explanation of the occurrence of the authigenic titanium minerals. For convenience the points of evidence will be referred to by the paragraph numbers used above.

It is likely that the greater part of the anatase and brookite in the Middle Jurassic was derived in some way from ilmenite. This mineral is abundant in the south of the region (6) and it is probable that the material laid down in the northern part was originally also rich in ilmenite. Many facts can be explained on the assumption that ilmenite suffered alteration in the margins of the region of deposition before the sediments were deeply buried, the first products being the hydrated oxides of iron and titanium. Where conditions were favourable for crystallization anatase would be formed by loss of water. Anatase always appears to contain some iron and under oxidizing conditions the iron would be in the ferric form tending to give a yellow colour to the tabular crystals formed in the unconsolidated sediments still not far removed from atmospheric action. If such crystals were formed rapidly (in the geological sense) at no great depth, slight tectonic movements and consequent local erosion would tend to distribute anatase plates in a slightly worn condition towards the more southern part of the region since the main direction of transport was from the NNW. Owing to their tabular form the sorting action of water might separate them from the detritus amongst which they had grown and distribute them amongst finer sediments (1), only the exceptionally large grains remaining near the place where they had been formed (8). In spite of this sorting action the average size of the detrital grains would be about the same as that of the authigenic grains (5).[1] The distribution of such newly formed anatase would only occur when there were local uplifts in the marginal areas, and would thus be relatively abundant at some horizons and scarce at others (9).


33
34
35
NORTH SEA
42
43
44
52
53
54
FREQUENCY OF AUTHIGENIC BROOKITE
F > 2·5
OCCURRENCE OF BLUE PYRAMIDAL AUTHIGENIC ANATASE
F > 0

Text-fig. 6.—The Distribution of Authigenic Brookite and Blue Pyramidal Authigenic Anatase in the Lower and Middle Estuarine Series (combined). Scale: 1 inch = 16 miles.

Nearer the centre of the region of deposition and particularly along the Cleveland axis the deposited material was more rapidly buried. Here such anatase as had formed would be small, and if it continued to grow would do so under much different conditions. Free oxygen might be absent and such iron as entered into the composition of anatase might be in the ferrous condition tending to form bluish crystals, whilst the greater pressure and closer packing of the grains might favour a habit which would make best use of the available space, i.e. crystals in which the pyramid is well developed (4). In beds where anatase had not begun to form the titanium dioxide in this region crystallized as brookite (3, 10). Some of the brookite is tabular on 100, some is tabular on 001 (Rastall, 1932; Phillips, 1932); but although the distribution of these habits has been studied cartographically no clue as to what decides the habit of this mineral has been found. There is no evidence that anatase of pyramidal habit or brookite of any kind formed in these sediments was redistributed as a result of penecontemporaneous erosion. Pyramidal anatase does occur as detrital grains but its size and its distribution point to some pre-Jurassic source. The detrital brookite of 100 habit which is found in the Middle Jurassic is extremely scarce and has not the appearance of the Middle Jurassic authigenic grains; whilst detrital brookite of 001 habit has not been observed at all. For these reasons it has been concluded that the authigenic pyramidal forms of anatase, together with all the authigenic brookite, have been formed at depth, and that the tabular forms of anatase were formed near the surface.

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[1] So far as *size* is concerned it would be possible to attribute most of the detrital plates to Triassic and perhaps other sources, but the distribution of the grains and certain of their varietal features lend support to the explanation adopted above.

Why leucoxene is also abundant where the crystallized forms of titanium dioxide are conspicuous requires some explanation. For the formation of crystals it was probably necessary for the titanium to pass into solution, and if we assume that it could do so only in limited amounts and under certain conditions then it is possible to understand the formation of the well-formed crystals of anatase or brookite side by side with the apparently non-crystalline grains of leucoxene.

THE RELATIVE STABILITY OF DETRITAL MINERALS

The decomposition of detrital minerals during the great lapses of time when they lie buried in the earth's crust is imperfectly understood and perhaps it has not always been clearly distinguished from changes due to weathering. Professor P. G. H. Boswell (1933, pp. 37–46) has summarized much of the available data on the stability of detrital minerals. Later two Dutch geologists, Drs. C. H. Edelman and D. J. Doeglas (1934), have described the etching of staurolite, garnet, kyanite, etc., and have discussed its significance. Whilst they regard the phenomenon as capable of lessening the value of heavy mineral assemblages as a means of interpreting the genesis of a sediment, they suggest that the phenomenon, so far as it concerns the above-named minerals, is so rare as to be of no great importance to the petrographer. Their examples are drawn from the Kainozoic and Upper Cretaceous, and it is possible without questioning the accuracy of their work to suggest that in the Jurassic and older systems the decomposition of these minerals may attain much greater importance.

The fact that some of the detrital species in the Mesozoic rocks of Yorkshire have suffered decomposition in varying degrees causes one to wonder whether there may have been other minerals originally present which in the course of geological time have totally disappeared. The minerals present are such that if they were derived from crystalline rocks they might be associated with such common rock-forming minerals as the amphiboles and pyroxenes; but the writer has been able to record no minerals from these groups except for three grains of glaucophane from the Dogger near Leavening (1934, p. 193) and three very doubtful grains of pyroxene in the Trias (1931, p. 137).

Dr. C. H. Edelman (1931) has described the etching and progressive decomposition of augite, hypersthene, and hornblende, stating that the phenomenon is frequently observed in Kainozoic sediments.

In the list given below an attempt has been made to arrange detrital heavy minerals in the order of their relative stability. The positions assigned to apatite and kyanite may cause some surprise, but they appear to be valid for the sediments which the writer has examined (see examples in Text-fig. 2). Ilmenite and magnetite should probably appear somewhere in the middle of the list, though their exact position is very doubtful. A group of *very unstable* minerals is provided to accommodate such minerals

Tentative List of Detrital Minerals Arranged in Order of Relative Stability

Very Unstable:	Ferromagnesian minerals, etc.
Unstable:	Kyanite
	Staurolite
	Garnet
Somewhat Unstable:	Monazite
Stable:	Apatite [1]
	Tourmaline
	Rutile
	Zircon

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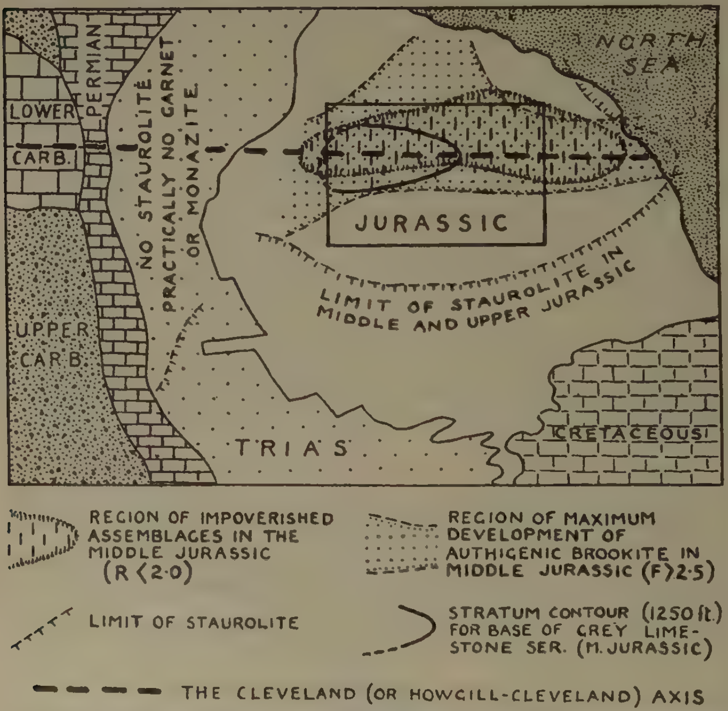
[1] Stable within the earth's crust, decomposed in weathered rocks.

as the pyroxenes and amphiboles. There is some evidence that certain minerals, e.g. calcite, retard decomposition and perhaps modify the sequence in which the detrital species are attacked.

Conclusion

It seems impossible to avoid the conclusion that in Yorkshire, along a belt coinciding with the Cleveland axis, mineralogical changes have been extremely active (Text-fig. 7). With regard to the decomposition of garnet, staurolite, and possibly monazite, and to the general impoverishment of the detrital suite, we have evidence that these changes affected both the Triassic and Jurassic rocks along this belt. Other changes, such as the regional development of authigenic brookite and of outgrowths on zircon, appear to be confined to the Jurassic.


LOWER
CARB.
PERMIAN
NO STAUROLITE
PRACTICALLY NO GARNET
OR MONAZITE
NORTH SEA
JURASSIC
LIMIT OF STAUROLITE IN MIDDLE AND UPPER JURASSIC
UPPER CARB.
TRIAS
CRETACEOUS
REGION OF IMPOVERISHED ASSEMBLAGES IN THE MIDDLE JURASSIC (R < 2·0)
REGION OF MAXIMUM DEVELOPMENT OF AUTHIGENIC BROOKITE IN MIDDLE JURASSIC (F > 2·5)
LIMIT OF STAUROLITE
STRATUM CONTOUR (1250 ft.) FOR BASE OF GREY LIME-STONE SER. (M. JURASSIC)
THE CLEVELAND (OR HOWGILL-CLEVELAND) AXIS

Text-fig. 7.—Map of North-East Yorkshire showing the relation between Mineral Alteration and Tectonics. The position of Sheet 43 is indicated to facilitate comparison with the other maps. Scale: 1 inch = 16 miles.

It is now necessary to consider what is the relationship between the Cleveland axis and the mineralogical changes apparently associated with it. The region of the axis in North-East Yorkshire is now revealed to us as a dome, but it appears that during the greater part of Jurassic times it was a subsiding basin in which each successive formation was deposited as an oval " lens ". We may suppose that in the most deeply buried portions chemical changes were most active and that minerals such as garnet, which if sealed in an igneous rock would have been stable, suffered decomposition when in the presence of subterranean waters at high pressure. The subsequent uplift and erosion of the region has revealed the once deeply buried sediments. One would anticipate that in general the region of impoverishment would be most extensive in the lower horizons although protective influences might cause exceptions to this rule.

The phenomenon of mineral decomposition in sediments appears, therefore, to be of such importance that failure to take it properly into consideration may lead the petrographer to draw erroneous conclusions, particularly on questions of provenance. For example, in discussing the sources of detrital minerals the writer in an earlier paper (1931, pp. 147–151) used the distribution of staurolite and garnet as important clues. Now in these rocks, where there is no palaeontological evidence of the relative geological ages of the scattered exposures, there are at least three possible factors which may cause differences in the heavy mineral assemblages in different localities :—

(i) The existence of two contemporaneous distributive provinces,
(ii) Differences in the age of the rocks,
(iii) Alteration of minerals subsequent to deposition.

In 1931 the writer believed that the first factor had been of such great importance that it obscured the differences due to the second ; and that it was necessary to consider the third factor only in the case of apatite. It is now clear that regional alteration is a factor of major importance especially in the case of garnet and staurolite. It must therefore be admitted that the evidence for the existence of two distributive provinces in so far as it was applied to Yorkshire seems to be invalid, whilst its validity in other areas requires re-examination.

To take another example, Dr. R. H. Rastall (1932, pp. 98–9), in dealing with the Middle Jurassic sandstones of Eskdale, has expressed the view that, because of the absence of garnet and of so many other minerals, the material cannot have been derived from the Carboniferous rocks or from any other known source. In addition to the problem of finding a source for such an assemblage there is the further difficulty as to how the material could have entered the area, since the Eskdale rocks are apparently encircled [1] by contemporaneous sandstones with a garnetiferous suite. But if the impoverishment of the suite has been brought about *after* deposition the difficulties of assigning a possible source to the Middle Jurassic detritus and of discovering a manner in which it could have entered the area at once disappear.

The writer is indebted to Mr. G. M. Davies not only for his critical reading of the MS. but also for valuable and encouraging discussions upon the petrological problems involved in this paper and the three papers (1939) on statistical methods in sedimentary petrology.

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[1] Complete encirclement, though it is suggested by the frequency map for garnet (Text-fig. 1), cannot be proved, for the position of the present coastline denies us evidence in the East. It would be possible to argue that an impoverished suite might have entered the area from this direction, but there is other evidence to show that most of the detritus came from other directions.

Some Observations on the Geology of Antigua, West Indies

By C. T. Trechmann

A RECENT short stay on Antigua has enabled me to inquire into a few points in the geology of that island. Among the matters of interest were to investigate the crucial question of the age of the Seaforth Limestone, which carries with it the age of the volcanic mountainous part of the island. Also to inquire into the supposed occurrence of Cretaceous Chalk at Cassada Gardens; to see some of the igneous intrusions in the Central plain and the Antigua Limestone; to collect the fresh-water mollusca of the silicified tuff beds; and to search the Antigua Limestone for the so-called "Oligocene rudist", *Neomonopleura* (*Rothpletzia*), which Dr. Lehner told me he thought occurred at Hodge's Bay. The sub-fossil land shells in the Pleistocene marls at St. George's Church also interested me, among other matters.

1. The Seaforth Limestone

The age of this limestone is a critical matter in Antiguan geology because it is concerned also with the age of the igneous and mountaineous southern and south-western parts of the island. Purves [1] did not mention it; J. W. Spencer [2] saw no fossils in it, but suggests it may be Cretaceous; Brown [3] and Earle [4] have attributed it questionably to the Eocene or Oligocene. This distinctly massive limestone, 50 or 60 feet thick, forms the higher part and the eastern side of a small rather isolated hill: its general dip is not easy to determine but seems to be a few degrees east. On the west side of the base of the hill it rests on a light-coloured, bedded, conglomeratic material which is exposed on the coast round the seaward side of the hill. The westerly or basal part of the limestone between the sea and the road passes down into white, thinly bedded, calcareous tuffs in which small coral masses occur. The more massive limestone higher up is grey in colour and crystalline in nature, and weathers in jagged surfaces and detached fallen masses. Fossils are not well preserved, being obscured by crystallization, but on the west side, a little way off the road on some weathered surfaces of the lower part of the exposure, I found a few sections of

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[1] *Bull. Mus. Roy. Hist. Nat. Belg.*, iii, 1884–5.

[2] *Quart. Journ. Geol. Soc.*, lvii, 1901, 494.

[3] A. P. Brown, *Proc. Acad. Nat. Sci. Philadelphia*, 1913.

[4] K. W. Earle, *Antigua Govt. Printing Office*, 1923.

Orthaulax, fragments of *Pecten*, *Lima*, and many small corals. The middle and more massive part of the limestone yielded a number of corals, while the higher part facing east shows the foraminifera, mostly of the genus *Lepidocyclina*, on the weathered and jagged surfaces. The limestone rests on tuffs and agglomerates and seems to occupy a position high up in the series of volcanic debris and igneous rocks; but at Seaforth its relation to the overlying beds is not very clear, though it is covered in places by more tuffs. It is hard, crystalline, splintery, and partly silicified, very unlike the yellow marly limestones of the Antigua Formation. Probably subsequently to its deposition it was affected and indurated by emanations from the igneous formations underlying and adjacent to it. The fossils, however, suggest that it cannot be very greatly older than the Antigua Limestone and one may also presumably conclude that the great mountainous series, rising to about 1,330 feet, of igneous eruptions and ejectamenta is also of Tertiary age, probably lower Oligocene, or somewhat older than the Seaforth Limestone.

Fossils of the Seaforth Limestone

Dr. C. D. Ovey kindly supplied me with the results of his examination of the foraminifera; these comprise two species.

Lepidocyclina (*Eulepidina*) *favosa* Cushman.

Recorded from the base of the Upper Eocene to the Middle Oligocene in the Tampico Area, Mexico (= upper part of the Upper Chapapote and Lower Alazan). See Nuttall, *World Petroleum Congr.*, 1933, reprint No. 28. Recorded by Vaughan from the Oligocene of Mexico, Georgia, and Antigua.

Lepidocyclina (*Eulepidina*) *undosa* Cushman.

Type specimen is from High Point, Antigua, collected by Vaughan. Other material apparently referable to this species is from Wetherell Point (Cushman, *Carnegie Inst. Washington*, No. 291, 1919, p. 65, pl. 3, figs. 1*a*, 2, 8, 9, pl. 15, fig. 5). Recorded as Middle Oligocene.

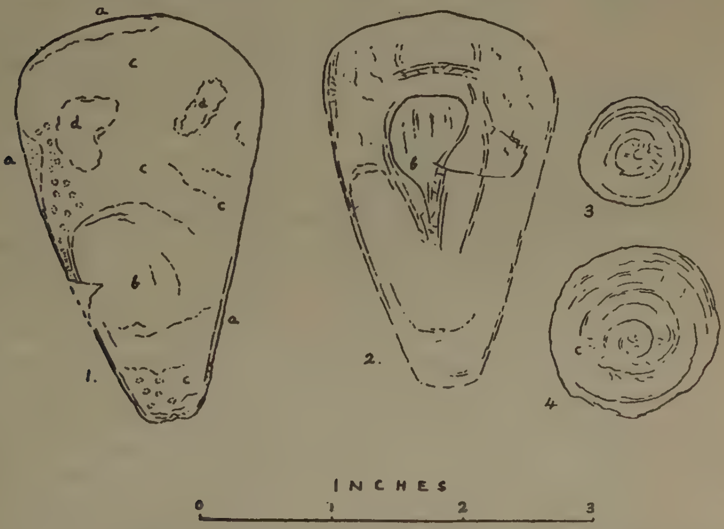
Synonyms: *L. gigas* Cushman (*vide* Vaughan) and *L. undulata* Cushman.

I may remark that the foraminifera of the Seaforth Limestone are very much less in size (up to 20 mm.) than the giants one sees in the Antigua Limestone at Hodge's Bay, High Point, and other localities which attain in some specimens a diameter of 90 mm.

Dr. H. Dighton Thomas has kindly undertaken to examine the corals I collected in the Seaforth Limestone.

Orthaulax seaforthensis sp. nov. Text-fig. 1

Description.—Shell cone-like, 76 mm. long and 48 mm. wide, sides tapering, straight, or very gently arched, surface apparently smooth, apical end gently rounded, the actual central part of the apex scarcely projecting ; the sides make an angle of 50–55° with the slope of the apex, the surface of which is smooth. The weathered detached apices show that the circumference of the shell was approximately circular, with only a slight tendency to blunt angularity. The apical part and to some extent the anterior end are well filled with calcareous material, the sides towards the anterior are thin, allowing a considerable space that the animal must have occupied. The shell has been eroded by boring organisms, the holes of which open on the surface.



TEXT-FIG. 1.—*Orthaulax seaforthensis*. Sp. nov. Seaforth limestone. Antigua. 1 : Partly weathered specimen. 2 : The same specimen broken longitudinally. 3 and 4 : Calcified apices, turned upside down and weathered out on the rock surface. (*a*) The smooth outer layer of the shell. (*b*) Whorls of the living chamber filled with limestone. (*c*) Calcite-filled apical and anterior parts of the shell more or less penetrated by boring organisms. (*d*) Hollow spaces in the calcite-filled apex.

Locality.—Lower part of the Seaforth Limestone on weathered surfaces of the hard grey rock ; a partly eroded specimen showing the outline, interior structure, and part of the external surface; and two weathered pieces of the calcite-filled apex, with more fragmentary material. Horizon probably low in the Oligocene.

Affinities.—It is about the same width as and has the conical form of *O. conoides* Woodring,[1] but the description of that species is accompanied only by figures of two sections and a weathered individual, all lacking the anterior end. In *O. conoides* the angle of the sides and apex is 90° and the actual apex is more protuberant. It is thought to belong to the Middle Oligocene (Rupelian) or the equivalent of the Antigua Limestone, and is therefore later than the Seaforth Limestone species. The more familiar *O. aguadillensis* Maury, of the Upper Oligocene and Lower Miocene, has much more rounded shoulders and a higher apex and the apical circumference is bluntly quadrangular. *O. pugnax* Heilprin, of the Oligocene of Anguilla, and *O. inornatus* Gabb, of the Oligocene of Cuba, Florida, etc., are species with more elevated spires and more fusiform outline.

Orthaulax is a peculiar stromboid mollusc which mimics the *Actaeonellae* of the Cretaceous, or *Itiera* of the Upper Jurassic. It is said to occur only in the tropical and sub-tropical faunas of the Middle Oligocene (Rupelian) to Lower Miocene (Burdigalian) in the West Indies, Central America, Mexico, and south-eastern U.S. America. C. W. Cooke[2] says the range in time of *Orthaulax* "straddles the greater part of the Oligocene and Lower Miocene". Dall says it does not appear in the Vicksburgian fauna or the nummulitic Ocala beds of Florida and seems to have become extinct before the development of the Oak Grove, Florida, fauna.

Spencer collected *O. pugnax* in the Antigua Formation of Antigua, referred to the Middle Oligocene. This species differs from the shell I collected at Seaforth, so, to avoid having another fossil without a name, I have named it after the locality. The state of preservation, one side weathered out of hard rock and the other broken across the living chamber, does not facilitate description, and its characters are perhaps best illustrated by a drawing, Text-fig. 1.

Pecten sp. indet.

Almost the only other mollusc seen in the Seaforth Limestone accompanying *Orthaulax* was a flattish imperfect *Pecten* valve with one auricle visible. Its height is about 25 mm., width about 24 mm., the ear 6 mm.; surface having about twenty-five regular ribs which diminish in size towards the edges, and which are rather broader than the interspaces. It is too meagre to identify, but has rather the shape of *Pecten* (*Chlamys*) *waylandi* Cooke, from the Oligocene of Santiago, Cuba, or *P. crocus* Cooke,[1] of the Oligocene of Crocus Bay, Anguilla.

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[1] *Proc. U.S. Nat. Mus.* (No. 2491), 1923, lxiv, Art. 1, 9, pl. 2, figs. 1, 2, 7.

[2] *Orthaulax*, a Tertiary guide fossil, *U.S. Geol. Surv. Prof. Paper* 129B, 1921, 23–31.

2. THE REPORTED OCCURRENCE OF CRETACEOUS CHALK IN ANTIGUA

Mr. W. R. Forrest kindly gave me a piece of the white chalky material that had come out of an old well situated at the Cassada Gardens, near a small railway line and the golf links. Some 500 yards away to the north-east the rising slope of the Antigua Limestone formation is seen. Near to the well at the golf links the bed rock crops out beneath the Cassada gravels, and consists of old volcanic tuffs, thinly bedded and highly silicified, the inside of each lump being very dense, containing large clear quartz grains.

It was recorded that the well passed through Cassada Garden gravels, and at a depth of 43 feet the white chalk was met with and this continued to the bottom of the well at 56 feet. There are now two wells alongside one another, one containing water, the other dried mud. So far as I could see down, some 12 feet or so, the sides are composed of slightly dipping beds of gravel and finer-grained material.

Mr. Forrest told me that he was away in England when the chalk was taken out and did not see it in situ. The well is a very old one dug many years ago; the water had risen, and it was decided to deepen it when the chalk was found in the bottom. Some cartloads of it were taken out, most of which was carried away by the natives for medicinal purposes, as it is strongly saline or salt-impregnated. Mr. Forrest assured me that the chalk occupied a part of the well not previously dug into but also that some bottles of a very old type were found on top of the chalky material. It seems to me unlikely that a bed of soft chalk should exist beneath the hard silicified tuffs and other beds of the central plain of the island. Mr. H. C. Rose, manager of the wireless station in Barbados, who is interested in microscopic and other scientific work and whose son John accompanied me to Antigua and is a keen local geologist, informs me that in Barbados chalk used to be imported and put down wells to purify the water. Charcoal was also used for a similar purpose, and chalk was formerly used as a packing for bottles of sulphuric acid. Cushman[1] regards this Antigua chalk as the equivalent of the Taylor Marl of Texas or the Craie Blanche (Senonian) of the Paris Basin.

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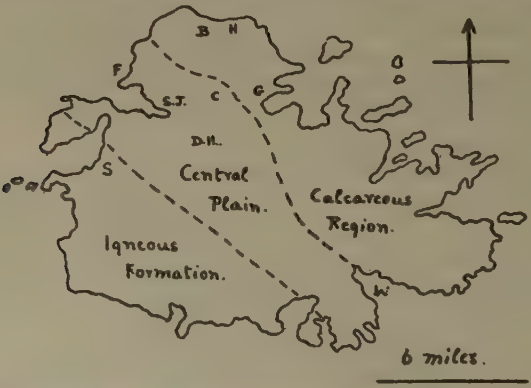
[1] *Publ. Carnegie Inst. Washington*, No. 291, 1919, pp. 131, 135, pl. 7, figs. 4*a*, *b*, and pl. 9, figs. 2*a*, *b*.

Taking these matters into consideration I personally should hesitate to accept this occurrence of chalk down an old well as evidence for the existence of Cretaceous rocks in Antigua.

Somewhat sweeping conclusions have been drawn from it, namely that Antigua lies more or less on a straight line between the Islands of Desirade and St. Bartholomew where plutonic quartz-diorite rocks of a supposed buried ridge come to the surface. Apart from Trinidad and Tobago on the south and the Virgin Islands to the north, no rocks of Cretaceous age have been recorded from the Lesser Antilles other than this chalk in Antigua.

3. THE BASALTIC INTRUSION AT CROSBIES

At Crosbies Mill, on a rise about a mile from the north coast, there is a small basic intrusion. A new road-clearing leading southwards from the farmstead showed several fresh lumps of a black basalt embedded in a decomposed matrix; the basalt comes up in the midst of a slightly arched mass of thickly bedded Antigua white limestone, and the intrusion terminates upwards



TEXT-FIG. 2.—Locality sketch-map of Antigua. SJ., St. John's; S., Seaforth; F., Fort James and James Bay; B., Basalt at Crosbies; H., Hodges Bay; C., Cassada Gardens; DH., Drew's Hill; W., Willoughby Bay; G., St. George's Church.

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[1] Cretaceous Foraminifera from Antigua, B.W.I. *Contrib. Cushman Lab. Foram. Research*, vii, pt. 2, 1931.

here. At the junction above the basalt there are a few inches of a soapy steatitic or chloritic material enclosing whitish flecks of apparently decomposed felspars ; and above this, and between it and the limestone, a foot or so of burnt-looking, friable, powdery or rubbly substance. Above this is the rather massive white limestone, the bedding of which does not seem to be disturbed by the intrusion. Its continuation can be traced for some yards away from the road into the bush, but the visible outcrop is very restricted.

This intrusion is evidently a dyke, as K. W. Earle records seeing it on the shore cutting the limestone and running roughly north and south, but says it consists there of only a soft brown deposit due to decomposition. Purves calls it a typical dolerite or basalt, hard, black, subcrystalline, with triclinic felspars, fragmentary augite crystals, many grains or cubes of magnetite, and a little olivine—the only example of this rock he could see in the island.

The rubbly layer I have referred to is not decomposed basalt, but is very suggestive of similar material in some sections in Jamaica, for instance at the Lazaretto, Mt. Diablo, etc., but at the latter place the layer of scorched-looking rubble contains pieces of white limestone in various stages of albitization, transfusion, or marmorization. It seems to be a feature connected with certain types of intrusion met with in the Antillean region.

Professor A. Holmes writes on the olivine-basalt at Crosbies : " This is a typical olivine-basalt containing microphenocrysts of olivine (now largely replaced by serpentine and carbonates) and labradorite. The main mass of the rock is a plexus of labradorite laths showing a tendency to fluidal orientation (microtrachytic texture), associated with intergranular augite, rare grains of altered olivine, specks of black ore, and some interstitial serpentine."

4. DREW'S HILL, " TRACHYDOLERITE "

A saddle-like ridge, 356 feet high, extending north-west to south-east and projecting from the gently undulating beds of the central plain, seems to be a small laccolithic intrusion. It was called a " Trachydolerite " by Purves, and is hard and greyish-green in colour with a rough fracture. Purves said that it differs from the igneous rocks that form the mountains of the south part of the island, but Earle questions this and says the rock seems to consist of two generations of triclinic felspar, possibly andesine, with a little accessory magnetite and possibly quartz and olivine in the groundmass. He goes on to say that it is in fact an andesite and does not differ essentially from the earlier volcanic rocks.

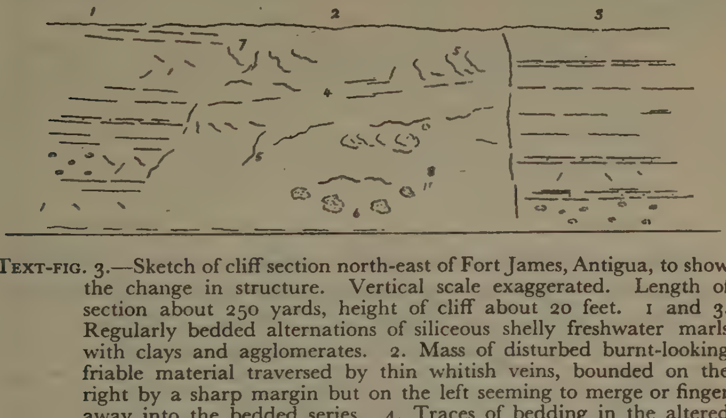
At its south-eastern slope it contacts with the sedimentary cherts, limestone, and tuffs which seem to dip away off the igneous mass. At the contact the material consists of mottled green and reddish rock looking like a " tuff " but made up of pieces of igneous rock welded together with silicified or hornfelsed portions of the adjacent sedimentaries. Some of the igneous fragments here contain clear quartz grains which seem to have been supplied by the enclosing matrix, making them look like a quartz-porphyry. Silicified corals and wood are also found in the tuffs near by. In Antigua, as in Jamaica, several occurrences suggest that there has been a metasomatism of sedimentaries into igneous-like rocks on a scale greater than a merely marginal assimilation. Professor A. Holmes reports on a slice of the " trachydolerite " of Drew's Hill, taken from the main mass of the rock, not the marginal portion: " The slide shows irregular phenocrysts of oligoclase and alkali felspar, both having refractive indices below that of canada balsam, margined by a clear fringe of fresh labradorite, strongly zoned, which often forms stout laths projecting into the groundmass. The cores of oligoclase and alkali felspar are angular or rounded, some are aggregates of several individuals, and they differ conspicuously from the clear rims in being cloudy as a result of alteration to sericite, epidote, chlorite, etc. The groundmass contains clear laths of labradorite, like that of the rims, with interstitial chlorite, epidote, and felsic material, the latter being mostly alkali felspar. Grains of augite are common against the epidote, and here and there well-shaped prismatic augite and possibly some rhombic pyroxene have developed. Grains and sharply crystallized cubes of black ore are sporadically distributed.

The altered cores of the phenocrysts are almost certainly xenocrysts from a felspathic plutonic rock such as granodiorite. No xenocrystic quartz can be detected, but this may have been transformed into the interstitial felsic material of the present rock. The rock as a whole is a hybrid such as might be expected to form by the incorporation and partial assimilation of the minerals of granodiorite by a basaltic magma. Further evidence from hand specimens and field observations are desirable to support this inference."

For a similar case, with well-established field evidence, see L. T. Nel, Geology of the Klerksdorp-Ventersdorp Area, *Geol. Surv. South Africa*, 1935, 99.

5. James Bay, North-East of St. John's (Text-fig. 3)

Northwards from Fort James a succession of three or four thin beds of one-time freshwater shelly marls, now almost completely silicified and flinty, alternate with bedded clays and agglomerates. The whole, very regularly bedded, is about 40 feet thick, forming a bay and two headlands, and is bent in the form of a gentle anticline. About a quarter of a mile along the exposure a surprisingly sudden change takes place; the cliff section becomes brown and red and burnt looking and the beds very disturbed for about 100 paces. At the south-west margin the junction is sharp and vertical, looking like the edge of a dyke or a small fault, but at the farther end of the disturbed portion the brown rubbly-looking material merges or fingers away among the bedded series which then resumes its previous normal character.



Text-fig. 3.—Sketch of cliff section north-east of Fort James, Antigua, to show the change in structure. Vertical scale exaggerated. Length of section about 250 yards, height of cliff about 20 feet. 1 and 3. Regularly bedded alternations of siliceous shelly freshwater marls with clays and agglomerates. 2. Mass of disturbed burnt-looking friable material traversed by thin whitish veins, bounded on the right by a sharp margin but on the left seeming to merge or finger away into the bedded series. 4. Traces of bedding in the altered material. 5. Thin veins of saponitic ? material. 6. Segregations of crystals, lapilli, etc., in a calcareous matrix. 7. Veined purple rubble. 8. Purple or green friable rubble.

The series loses completely its regular bedding, becomes veined in all directions by thin whitish veins, the material takes on a scorched appearance and is made up of small lapillus-like andesitic fragments, ferruginous and greenish siliceous pellets, green transparent crystals and grains of pyroxene and clear transparent crystals of andesine[1]; all in places embedded in a friable matrix of crystalline calcite. In parts a bedded character can still be traced in this mass of abnormal material.

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[1] These minerals were kindly determined by the Mineralogical Department of the British Museum (Natural History).

I am at a loss to say whether this curious sudden change in the otherwise undisturbed bedded series is due to conditions operating during deposition, or whether it is the result of gaseous emanations possibly connected with some underlying intrusion and exerting a pneumatolitic action. Its shape suggests a dyke-like intrusion, but the material is quite tuffaceous in appearance.[1]

Apparently there are other occurrences of a similar character in Antigua, as Earle describes intrusions in the tuff series, and remarks that " at the south-east end of the island the true igneous mass did not reach the surface except in the form of agglomerates ".

Freshwater Mollusca of the Silicified Beds at James Bay

The following species have been recorded from the freshwater beds that extend across the central plain from north-west to south-east :—

Hemisinus antiguensis Brown and Pilsbry
,, *siliceus* ,, ,,
,, *latus* ,, ,,
,, *atriformis* Cooke
Bythinella antiguensis Brown and Pilsbry
Planorbis siliceus ,, ,,

Cooke includes all the *Melania*-like shells in the genus *Hemisinus* of Swainson. Several authors state this genus to be smooth but on a specimen I collected, apparently of *H. siliceus*, the early whorls have fine longitudinal striae or regular enlargements of the growth lines. They are decidedly reminiscent of some forms of the genus *Pachycheilus* Lea, which now inhabits Mexico, Central America, Cuba, etc. These living genera seem to be distinguished by the nature of the operculum and so this test cannot be applied to the fossils.

H. antiguensis is a slender, many whorled, and highly decorated, partly reticulate form, which, except that it has rather deeper sutures, scarcely differs from the living *Melania* (*Melanoides*) *tuberculata* Müll. This is an Old World species and is unlike those of the American continent ; it has a wide distribution—the Sahara, Palestine, India, Mauritius, Japan, etc. However specimens from India and the East seem to me to differ from those of North Africa and Palestine and are probably in fact distinct. These Oligocene Melanias of Antigua may represent forms ancestral to present day Old and New World genera.

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[1] It calls to mind some rather similar occurrences in Jamaica apparently connected with a reheating of the Laramide complex in Tertiary times.

The silicified *Planorbis* of Antigua has much the shape of certain living forms from North America, such as *P. deflectus* Say.

6. FOSSILS OF THE ANTIGUA LIMESTONE AT HODGE'S BAY

Neomonopleura (*Hipponix* or *Rothpletzia*) *wiedenmayeri* Hodson and Harris

Dr. E. Lehner sent to Dr. R. Rutsch in Basel some specimens which he thought were probably the attached valves of this fossil; the specimens, as Dr. Lehner told me, were crushed. He collected them in the Antigua Limestone at Hodge's Bay on the north coast, where the rock is full of innumerable giant specimens of *Lepidocyclina gigas*. On visiting the locality I found a satisfactory uncrushed valve of this *Rothpletzia* and so can confirm the record, while not far away were several crushed specimens near to or attached to one another.

Its first and type record was from lithothamnial reef beds of supposed Miocene (Vindobonian) age of Gran Canaria in the Canary Islands.[1] This form was called *Hipponix* (*Rothpletzia*) *rudista* Simonelli. Later it was found to be plentiful in Morne Diablo quarry in south-west Trinidad in beds also lithothamnial and attributed to the Middle Oligocene. This shell which Hodson and Harris [2] described as an "Oligocene Rudistid" was shown by Rutsch [3] to be the genus *Rothpletzia* already recorded from the Canary Islands. Boehm had previously shown it to be a *Hipponix* adapted to a sessile life in the lithothamnial reefs, an abnormal capulid gastropod.[4]

Apart from an unconfirmed record from the Lutetian of the Vicentin-Veronese Alpine area, the genus is recorded only from the Canary Islands and the West Indies.

Among other fossils accompanying it is the rare *Epitonium* or *Scalaria antiguense* Brown, some very large gastropoda but so badly preserved as to be practically unidentifiable, numerous Pectens and echinoderms of the genus *Clypeaster*, and many other species.

From the marls at the base of the Antigua Limestone east of Cassada Gardens just above its junction with the tuffs of the

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[1] V. Simonelli, *Boll. Soc. Geol. Ital*, xi, 1892, 76.

[2] *Bull. Amer. Pal.*, xvi, 1931, 133.

[3] *Verh. Schweiz. Natf. Ges. Altdorf*, 1933, 373.

[4] R. Rutsch, Angebliche Rudisten aus dem Tertiär von Trinidad. *Eclogae geol. Helv.*, xxvii, No. 1, 1934, 1–9.

Central Plain I obtained some foraminifera which Dr. C. D. Ovey kindly determines as :—

Lepidocyclina canellei Lemoine and Douvillé—recorded from the Middle and Upper Oligocene of the Panama Canal Zone, Colombia, Venezuela, E. Mexico, Jamaica, Curaçao, Cayman Islands, Cuba, Trinidad, Martinique, and the Antigua Formation, Antigua ; also from the European Oligocene.

7. THE MARGINAL MARL BEDS

Near St. George's Church thin layers of clayey marl, some 10 feet above sea-level, overlie the Antigua Limestone and contain land and some marine shells. The former include *Helix* (*Pleurodonte*) *formosa* Fér., which now lives only in the mountainous igneous part of the island—the living ones are smaller than the fossils. With these are *Helicina crosbyi* Nob., which is thought to be extinct, and two bulimoid shells, one of them *Buliminus guadalupensis* Brug. This bed is very reminiscent of the post-coral-rock marls of Barbados, which occur round the margins of the more recently uplifted southern parts of that island, but are there raised to a higher level than on Antigua. The same three genera of land shells occur, but on Barbados the *Helix* is the local *Pleurodonte isabella* Fér. The *Helicina* also seems to be a large form of a local species, while the *Buliminus* resembles the species that occurs also on Antigua.

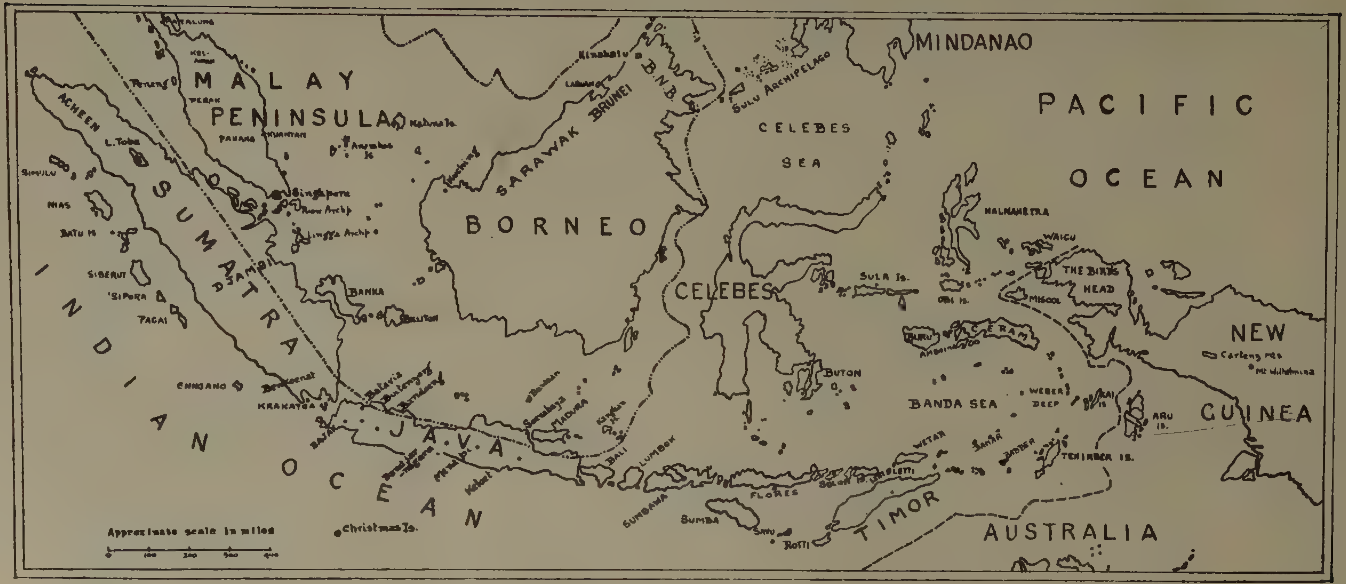
Geological Research in the Malay Peninsula and Archipelago

By J. B. SCRIVENOR

THIS paper is an attempt to review briefly the progress of geological research in an area familiar to zoologists as the classic ground covered by Alfred Russel Wallace, but which is also the field where Dutch geologists have for many years been carrying out valuable work on a much larger scale than has been possible in the smaller areas under British control in the Malay Peninsula and Borneo. There is a considerable amount of geological literature dealing with the Peninsula and Archipelago. In *The Geology of Malaya* (1931) is a bibliography of that concerning the Malay Peninsula, and in F. H. Hatch's translation of Posewitz's *Borneo* (1892) will be found lists of the earlier literature dealing with both the British and Dutch portions of that island. In the Malay Peninsula the *Journal of the Straits Branch of the Royal Asiatic Society* has included scientific papers since the appearance of their first number in 1878; and in 1927 C. E. Wurtzburg produced an index, including an earlier index by W. D. Barnes, of the *Journal* up to 1915, when the title of the society was changed to *The Malayan Branch of the Royal Asiatic Society*. In 1930 the Malayan Branch published an exceptionally interesting number containing a translation by H. V. Mills of Manoel Godinho de Eredia's *Description of Malacca, Meridional India and Cathay*, originally written about 1600 in Portuguese. This is the earliest known publication that can be called scientific about this part of Asia and contains information about tin and gold, also " traces of diamonds and emeralds as Pliny points out " which later workers have not been able to find.

The literature dealing with the Dutch possessions is mostly written in Dutch, but some is in English, French, or German. In 1925 H. A. Brouwer published an English *résumé* of a course of lectures given at Michigan University, which provides an excellent statement of results up to that date; and in 1927 L. M. R. Rutten published a much more extended account of the Netherlands East Indies in Dutch in the form of a series of addresses. In 1850 a Mijnwezen, or Mines Department, was established in Buitenzorg but was transferred later to Batavia and later again to Bandoeng as part of the Mijnbouw. In 1872 the first number of the *Jaarboek van het Mijnwezen* appeared, now the principal medium of publication for geological, general statistical, and administrative information ; but in addition to the *Jaarboek* there are the *Vulcanologische en Seismologische Mededeelingen* dating from 1921, the *Verslagen en Mededeelingen betreffende Indische Delfstoffen en hare Toepassingen* and other periodicals mentioned by Brouwer, who also gives a list of larger monographs not published in periodicals (1925, p. 142), among which are R. D. M. Verbeek's memoirs on *A Part of the West Coast of Sumatra*, *Krakatau*, and (with R. Fennema) *Java and Madoura*, also G. A. F. Molengraaf's *Geological Exploration in Central Borneo* (Leyden and Amsterdam, 1902) and Volz's *Nord Sumatra* (Berlin, 1912). In the British area an attempt was made after the Great War to establish a scientific journal for all branches on the lines of *The Philippine Journal of Science*, but as there was a disinclination to discontinue separate publications in Government scientific departments this journal unfortunately died a very early death. The *Journal of the Straits* (now *Malayan*) *Branch of the Royal Asiatic Society* has been a great help to geologists, but apart from that periodical and a few separate publications the Staff of the Geological Survey of the Federated Malay States have utilized as far as possible the facilities offered by well-known periodicals such as this Magazine and the *Quarterly Journal of the Geological Society of London*, with a view to making their work easily accessible. The writer's *Geology of Malaya* summarizes results up to 1931.

In 1929 the Fourth Pacific Science Congress was held in Java. The wealth of geological literature (in English) provided for the delegates, the lectures and excursions widened their knowledge considerably, but unfortunately some of the literature is not generally available now, for instance a book on Krakatoa which gives an account of the re-establishment of flora and fauna after the great eruption of 1883. In the years 1929 and 1930 the Snellius Expedition was working in the eastern part of the Dutch East Indies. The reports of this expedition contain much interesting geological matter, and mention should also be made here of *Gravity Expeditions at Sea* (1934), by F. A. Vening Meinesz. Vol. ii contains chapters by J. H. Umbgrove and Ph. H. Kuenen bearing on the tectonics of this region ; and four years later Umbgrove published a *Geological History of the East Indies* (1938), which is an excellent summary of seventy pages. In 1929 J. W. Gregory published a collection of contributions on Asiatic tectonics (*The Structure of Asia*) with short references to the East Indies and an abstract of a paper by Brouwer on *The Importance of Horizontal Movements in the East Indian Islands*. This book also contains sketch-maps purporting



Sketch-Map showing the chief localities mentioned in the text.

—·—·—·—·· Limit of the Sunda Shelf.

— — — — — — Limit of the Sahul Shelf.

to show the distribution of land and sea at various times in Asia, including the Archipelago.

STRATIGRAPHY

In England we honour the memory of several great leaders in stratigraphical research of the last century. In Malaysia, which is a convenient term sometimes used to cover the Peninsula and Archipelago, there is one outstanding name, that of R. D. M. Verbeek, in whose honour a *Commemoration Book* was published on the occasion of his eightieth birthday in 1925. In this book forty-five authors, of various nationalities, contributed papers. At the beginning of this century there still lingered opinions that some of the rocks of Malaysia must be of great antiquity because they were highly metamorphosed. In the Peninsula the writer was informed that limestone, now known to be Carboniferous, and a continuation of the Moulmein Limestone of Burma, was Archaean because it resembled the Laurentian Limestone of Canada. In the Archipelago the " Old Slate Formation " figured in early works, and in Posewitz's *Borneo* (1892) there are references that can be conveniently noted here. Discussing the age of the rocks forming the " mountain land " of Borneo, Posewitz said that the Old Slate Formation is Devonian, but that besides these slates crystalline rocks occur that crop out below them, for instance hornblende-schists, mica-schists and quartzites in south-eastern Borneo ; and added that they were much more likely to be of Archaean age and that a part of the quartzite-schist and clay-phyllites was perhaps of the same age ; while another part might belong to the Devonian. He quoted Verbeek as saying of the Old Slate Formation of Sumatra that perhaps a part of the schists were Azoic, but that the greater part is Silurian or Devonian or a mixture of both. Rutten (1927, p. 257) quotes Suess as saying that the territory between the Schwaner Mountains and Cape Sambar represents a *môle archéen* and gives other references to supposed Archaean rocks. This question of the oldest rocks exposed in Malaysia cannot be regarded as settled because there is still much exploratory work to be done. In the Shan States both Ordovician and Silurian rocks are known, but all that can be said at present about the oldest outcrops in Malaysia is that Carboniferous strata certainly occur and probably the Devonian is represented also. Umbgrove (1938) mentions possible Devonian localities in Dutch New Guinea, and, incidentally, one very uncertain claim to Silurian rocks based on the reported occurrence of *Halysites wallichii*. W. C. Klein in 1916 described a supposed Devonian trilobite fauna from Acheen, N. Sumatra, but P. Tesch referred the fauna, including *Neoproetus indicus* and *Phillipsia* aff. *sumatrensis*, to the Permian (Rutten, 1927, p. 448). In the Peninsula *Proetus* cf. *coddonensis* and *Phillipsia* aff. *silesica* were found with other fossils in Patalung and referred by F. R. Cowper Reed to the Culm (1920) and recently the writer has been informed of another Culm fauna with similar trilobites from Kuantan, Pahang. In Central Celebes the occurrence of *Popanoceras timorense* and *Spirifer verneuilli* in the collection of Colonel Verstege made Brouwer suggest that Devonian rocks might be present on that island (Rutten, 1927, pp. 620 and 625), but in his own book (1925, p. 12) Brouwer says under the heading " Older Palaeozoic " that these discoveries were not generally accepted.

In support of extensive Carboniferous outcrops in Borneo, Posewitz quoted the determination by Tenison Woods of certain fossil plants found in Sarawak as the Gondwana forms *Vertebraria* and *Phyllotheca* (1885). Commenting on this, Rutten (1927, pp. 270, 271) suggests there may have been a mistake because we have heard no more since 1885 of so remarkable a discovery as that of a Gondwana flora in Borneo. In 1929 O. Posthumus said that Tenison Woods's determination had not been confirmed and that on the other hand such fossil plants as he had been able to examine from the only coal-mine working in 1885 were dicotyledonous leaves and wood, which could not be Palaeozoic. The writer's experience in Sarawak showed (1927) that extensive outcrops mapped by Posewitz as Carboniferous in the vicinity of Kuching, the capital of Sarawak, are really Jurassic in which he found *Perisphinctes*, while the coal-bearing beds are certainly younger. Private information reached the author some years ago about Carboniferous fossils in Borneo, but no confirmation of this has been published yet.

Until the detailed mapping of the islands of the Archipelago has been advanced far beyond its present stage, it will be impossible to say that we are even approaching a complete record of the stratigraphical geology. In the Peninsula a general map has been produced which is admittedly in large part a sketch-map, but the Survey staff is now engaged in producing maps on the scale of one mile to the inch, of which four have been published. In the Archipelago the British portion of Borneo remains unmapped apart from private work done by oil-companies and the sketch-map published by Posewitz on the scale of fifty miles to an inch. In Dutch Borneo the Geological Survey staff is working on maps on the scale 1 : 250,000. In the southern part of Sumatra eleven sheets on the scale 1 : 200,000 have been published apart from earlier work. In Java, of which a geological map of twenty-six sheets on the scale 1 : 200,000 was produced by Verbeek and Fennema in 1896, a scheme is in operation for mapping the whole island again on the scale 1 : 100,000. When completed there will be 145 sheets of which eleven have been already published. Many maps of small areas in the Archipelago, and a few in the Peninsula have been published apart from this systematic work, and a general geological map on the scale 1 : 1,000,000 of the whole region is in course of preparation though every sheet cannot be complete. Sheet II of this map includes the Malay Peninsula and was prepared by the British and Dutch staffs in collaboration. Sheet XIII is of West New Guinea, at the other side of the region, published in 1930 by J. Zwierzycki.

Carboniferous or Permocarboniferous rocks occur in the Peninsula, Sumatra, and New Guinea. Lists of fossils identified will be found in Brouwer's book (1925) and in the writer's book (1931). The separation of Carboniferous from Permian strata is difficult in the Peninsula and Sumatra, where there is good evidence that they pass up into Triassic rocks without any important unconformity. In Timor, however, and other adjacent islands, Savu, Rotti, Letti, Luang, and Babber, a wonderfully rich fauna of echinoderms, cephalopods, brachiopods and corals has been found and is stated to be Permian. Commenting on the perfect state of preservation of these fossils Brouwer says (1925, 16, 17) :—

> " The perfect state of preservation of all these fossils and the abundance of new species, which are not found in deposits of the same age in other parts of the world, are to be explained by the tufaceous character of the rocks from which the largest collections of well-preserved fossils have been made. Apparently volcanic ash from active volcanoes killed the animals quite suddenly, at the same time covering them with a protecting bed of ash, so that such fragile parts as the calyx of the crinoids were well preserved. The nearest relatives of all the Permian faunas investigated up to the present time are to be found in the Permian of the Alps, of Sicily, of the Urals, of the Salt Range, and in the Himalayas, while the Permian sediments of Timor also correspond to a marked degree with the Wichita formation of North America."

Shallow-water Triassic rocks are widespread in the Peninsula, where no Triassic limestone has been yet proved to exist. *Myophoria*, *Halobia* and *Daonella* are characteristic fossils. In the Archipelago they are also extensive, occurring in Sumatra, Borneo, Buton, and in the islands to the south of Singapore (the Riouw Archipelago). In Timor and adjacent islands Triassic limestones are found with a rich fauna described briefly by Brouwer (1925, pp. 18–23). The distribution of these

Triassic rocks shows that to the north-west there was a land-mass, while in the south-east deep-sea conditions existed.

Jurassic rocks may be represented in Singapore, but owing to the smallness of the collections of fossils made there considerable doubt exists about this and the presence of even Rhaetic rocks has been queried (Scrivenor, 1931, pp. 65–68). The occurrence of *Podozamites lanceolatus*, *Carpolithes*, and other plant remains, shows that land was close at hand when these beds were laid down. In the Archipelago Jurassic rocks occur on Timor, Rotti, Letti, Ceram, Buru, Celebes, the Sula and Obi Islands, where the fauna is very rich, Borneo, Sumatra (probable), and New Guinea.

Cretaceous rocks are known in Timor, Rotti, Letti, the Tenimber Islands, Ceram, Buru, Celebes, the Sula Islands, Misool, New Guinea, Halmaheira, Sumatra, Java, and Borneo. *Orbitolina* and *Globigerina* occur in several localities.

It is impossible in the space available to give details about the distribution of these Palaeozoic and Mesozoic rocks or of the fauna and flora found in them, but there are two subjects connected with them that are of great interest and should be noticed here. The first of these is the discovery in Djambi (Middle Sumatra) of a flora described as Permocarboniferous by W. J. Jongmans and W. Gothan (1930). The plants figured are: *Calamites*, *Palaeostachya*, *Sphenophyllum*, *Lepidodendron*, *Stigmaria*, *Maroesia*, *Sphenopteris*, *Monocarpia*, *Pecopteris*, *Asterotheca*, *Tobleria*, *Aphlebia*, *Alethopteris*, *Macralethopteris*, *Callipteridium*, *Gigantopteris*, *Neuropteris*, *Taeniopteris*, *Cordaicarpus*, *Rhynchogonium*, *Carpolithus*, *Cordaites*, *Carpolithus*, *Trigonocarpus*, *Poacordaites*, *Cordaicladus*, and *Gigantospermum*. This flora is of Stephanian, or Upper Coal Measures age, and its occurrence so close to the *Glossopteris* flora of India is remarkable. In Kelantan the writer and H. E. F. Savage found *Pecopteris* and *Cordaites*, described by W. N. Edwards (1926), which indicate that on the Peninsula also there is a trace of the same flora. O. Posthumus searched the Sumatra locality for *Glossopteris* flora, but could not find any examples. Concerning these plant-remains, Posthumus says (1929, p. 379):—

> "The occurrence of this type of plants on Sumatra is especially interesting because this locality is situated just midway between British India and Australia which both possess a well-developed flora of the *Glossopteris* type. . . . These data lead us to believe that during the Lower Permian a south-western prolongation of the 'Chinese continent' extended there. The relationship of this region with the 'Angara continent' appears to me to be one of the most interesting geological problems of Eastern Asia."

The occurrence of *Alethopteris*, *Taeniopteris*, and *Pecopteris* in

Sumatra and *Podozamites* and *Carpolithes* in Singapore suggests a relationship with the Upper Gondwanas of India, but the Permocarboniferous or late Carboniferous age of the Sumatra fossil plants seems to be clearly demonstrated by Zwierzycki, Jongmans, and Gothan (1930). The last two say that the two horizons where the plants are found occur in close association with five beds of limestone with *Fusulina* and that they are between the lowest two of these five beds. A. C. Seward (1931, p. 234, etc.) mentions these Sumatra and Kelantan plants as proving that the northern flora of late Carboniferous or early Permian times wandered as far south as Malaya and Sumatra. The presence of *Gigantopteris* shows that it came by way of China and that in Palaeozoic times a land-mass lay close to the north with a fluctuating coastline, which in Triassic times became more stabilized. In the same work will be found a reference to the mixture of northern, Indian, and Chinese floras found in the Wankie coalfield of Rhodesia.

The other point of special interest is the occurrence of radiolaria in various rocks and their bearing on the problem of the origin of radiolarian cherts, whether they are of deep-sea or shallow-sea deposits. The chief contributor to this subject has been G. A. F. Molengraaf (1902), who described the Danau Formation of Central Borneo, which contains " radiolarites " associated with diabase, quartzite, clay-shales, and sandstone. The age of the Danau Formation is Jurassic, but may be partly Triassic. In 1929 four papers were published on radiolaria-bearing rocks in *De Mijningenieur*, the authors being J. H. Krol on those of Borneo, Ch. E. A. Harloff on those of Java, J. M. W. Nash on those of Sumatra, and the writer on those of the Peninsula. Krol, who quotes the writer's paper in this Magazine for June, 1912, and who has visited Sarawak as well as Dutch Borneo, classifies the rocks with radiolaria as follows: (1) more normal sediments, sandstones, marls, clay-slates, limestones, and tuffs; (2) siliceous rocks such as hornstone, jasper, cherts, and radiolarite, (3) conglomerates, etc., which contain pebbles of the above. Harloff describes red hornstone with radiolaria in the headwaters of the Loh River (Loh Oelo) associated with shale, slate, sandstone, tufaceous sandstone, marl, and limestone. The writer had the advantage of seeing one of the exposures referred to, interbedded limestone and chert with radiolaria, and of hearing the late Gustav Steinmann arguing with a well-known American geologist about the origin of the chert. Steinmann claimed it was abyssal but the American geologist replied that the presence of radiolaria was no proof of that because the Gulf of California is full of them.

The occurrence of *Orbitolina* shows these beds to be Cretaceous. Nash describes radiolaria-bearing rocks from several localities in Sumatra ; marly limestone, red-brown hornstone, brecciated hornstone, shale and slate, radiolarite, tuff, and tufaceous sediments. Nash mentions the radiolaria described by Hinde as evidence of Palaeozoic age in a rock from Billiton, but the Sumatra examples are believed to be Mesozoic in age and pebbles are found in a Tertiary conglomerate. In the Peninsula the greatest development of radiolarian cherts is found close to and in one case at least actually interbedded with quartzite. In no case is there good reason to suppose that the radiolaria-bearing rocks were laid down in an abyss of the ocean. With regard to the islands of the Archipelago, however, this conclusion cannot be stated with certainty. In 1912 the writer quoted Molengraaf on the Borneo cherts (1902, pp. 245, 246), and said :—

> " Anyone who reads Professor Molengraaf's views on the Central Borneo rocks will realize that his case for their being oceanic deposits . . . is so strong that those who would question it must examine the relations of the rocks in the field. The Peninsular cherts on the other hand, and probably the Billiton chert also, were laid down in a comparatively shallow sea, not out of reach of terrigenous material. The oceanic radiolarian rocks are not stated to contain any carbon ; the shallow-water radiolarian rocks are rich in carbon."

Since that was written, Brouwer has mentioned in his book (1925, p. 31)—

> " a most interesting occurrence of red deep-sea clay-shale of Upper Cretaceous age in the island of Timor. . . . Besides numerous nodules of manganese the clay-shale contains a great number of fragments of teeth, for the greater part of *Elasmobranchii*. . . . Remains of Radiolaria are found in the clay-shale and nodules with teeth which show exactly what might be expected from teeth found in deep-sea deposits. Some of the larger *Lamna* teeth, for instance, are in the same condition as those found by the Challenger and other expeditions in recent red clays from the deep sea."

This description sounds convincing, and there cannot be much doubt that the deposit is of deep-sea origin. With regard to the Peninsular cherts, examination of a large number of slides shows that very often there is not a trace of radiolaria, and that in some cases vegetable remains are present. The writer has figured coniferous tissue and vascular rootlets in chert (1931, pp. 78, 79) and L. H. Krol is quoted as saying that in Upper Sadong, Sarawak, he found under shale with *Monotis* a bed of chert two feet thick with rootlets of *Cedroxylon*. Posthumus (1929, p. 378) mentions this and also a rock that he considers to be possibly silicified peat in West Borneo. It cannot possibly be held that such chert, or chert with no visible radiolaria, is derived from radiolaria. The writer's experience points to conditions having existed that made water so rich in dissolved silica that some was precipitated as a gel ; and if this happened in sea-water the fact of the water being rich in dissolved silica would encourage the growth of siliceous organisms such as radiolaria whose shells would become entangled with the gel or fall into the mud that formed " shale with radiolaria ". It is significant that in most localities where cherts occur igneous rocks are abundant also, and, as has been suggested for British cherts, it is possible that emanations from submarine eruptions charged sea-water with silica. On the other hand anyone who has seen tropical weathering where the rainfall is heavy, knows that much silica is carried to the sea in solution. The presence of abyssal deposits in the Archipelago is not surprising, because at the present day Weber's Deep, in the Banda Sea, with many islands near it, exceeds 7,000 metres in depth, while greater depths are found east of the Philippines and equally great ones south of Java.

Brouwer (1925, p. 26 and plate vii) also mentions Upper Jurassic beds

> " which often show the characteristics of deep sea deposits. . . . In Rotti exceedingly well-preserved nodules of manganese are found in siliceous limestones and siliceous and calcareous clay-shale with nodules and flat concretions of chert which are full of tests of Radiolaria."

It would appear, therefore, that in Malaysia there are rocks with radiolaria that are both of deep and comparatively shallow water origin ; but it is doubtful if any chert can be said to consist entirely of the tests of radiolaria.

Tertiary rocks are widespread and of great thickness in the Archipelago, but in the Peninsula they have not been proved to exist. There are a few patches of freshwater beds with coal from which mollusca and plant-remains have been collected. The mollusca are *Paludinidae* (L. Cox, 1937). A short description of the plant-remains is given by the writer quoting H. N. Ridley (1931, p. 115), who said that the collection suggested a drier climate than we have at present, and that, on the whole, they are of a modern type. It was thought once that the nature of the coal in these beds pointed to Miocene age, but in Burma there are similar beds with coal or lignite that are thought to be late Tertiary or Pleistocene (Chhibber, 1934, pp. 261, 262, etc.). The Peninsular beds are thought to be lacustrine. No marine Tertiary beds are known with certainty, but in Perak an unfossiliferous limestone has been found with the Enggor coal.

The Tertiary strata of the Archipelago are best developed in the three large islands Borneo, Sumatra, and Java. Limestone is more abundant in the east of the Archipelago than in the west. In Java change in the grain of sediments indicates that they were derived from a land-mass lying to the south or south-west which Brouwer identifies with Gondwanaland (1925, p. 35).

The application of the European system of classification to these Tertiary beds is a very difficult matter, and although they are divided into Eocene, Oligocene, Miocene, and Pliocene it is more usual to speak of "Palaeogene" and "Neogene", the boundary between the two being equivalent to the top of the Aquitanian (Upper Oligocene). In a paper on the famous Trinil beds in which *Pithecanthropus erectus* was found, L. J. C. Van Es (1929) says that the first geologist to attempt correlating the Java Tertiary beds with those of Europe was J. Martin, who tried to base his classification on the number of fossil mollusca still living in neighbouring seas. Drawbacks to this method are that knowledge of living forms is not very great, and Van Es thinks that there is some possibility of quicker development in tropical seas. He thinks, however, that Martin's is the only useful method now available, and that it may become possible to correlate the Tertiary beds with those of Europe with the assistance of faunas in intervening countries, but much remains to be done.

Posthumus (1929, pp. 354, etc.) reviews descriptions of Tertiary flora in the Dutch East Indies. Goppert in 1854 concluded that the Tertiary flora closely resembled that of recent times. The same conclusion was reached by Heer in 1874 and 1879. Geyler, describing in 1877 specimens from South Borneo, agreed with the first two authors ; but in 1883 the work they had done was revised by Baron Von Ettingshausen, who expressed the opinion that the Tertiary flora of the Archipelago showed more affinities with the European flora of that period than with the recent flora of the Malayan region. Posthumus commented on the small value of the collections made, the specimens being nearly always parts of leaves only, and on the fact that the authors named above had never visited the tropics though the material could be studied successfully only by a man who had a large experience of Malayan flora, not only by working in herbaria, but also in the field. It appears that as a means of classifying the Tertiary beds of the Archipelago, present knowledge of the flora is useless.

Another method of classifying the Tertiary beds is by the foraminifera they contain. This method has been conveniently summarized by I. M. Van der Vlerk and J. H. F. Umbgrove (1927). These authors divided the Tertiary strata into seven divisions, the names of the European divisions and Palaeogene and Neogene being avoided. This paper gives excellent illustrations of the "guide-foraminifera", a table showing their distribution through the seven divisions, and another table showing the distribution of the divisions in the Archipelago and the nature of the beds. The distribution of the foraminifera, including those in Pleistocene and Recent beds, is as follows :—

Recent	*Alveolinella* (recent type), *Cycloclypeus*.
Pleistocene . . .	,, ,, ,,
Tertiary, not with *Orbitoidea*	,, ,, ,,
,, "f"	*Alveolinella* (recent type), *Alveolinella bontangensis*, *Cycloclypeus*, *Lepidocyclina*, *Miogypsina*, *Trillina howchini*.
,, "e"	*Alveolina*, *Cycloclypeus*, *Spiroclypeus*, *Lepidocyclina*, *Miogypsina*, *Trillina howchini*.
,, "d"	*Alveolina*, *Cycloclypeus ?*, *Lepidocyclina*, *Nummulites*.
,, "c"	*Alveolina*, *Nummulites*.
,, "b"	*Alveolina*, *Nummulites*, *Orthophragmina*, *Pellatispira*.
,, "a"	*Alveolina*, *Flosculina*, *Nummulites*, *Orthophragmina*, *Pellatispira*, *Assilina*.

In their table the authors showed *Heterostegina* as occurring in every division, not as a "guide-foraminifer" but because it can easily be mistaken for *Spiroclypeus* or *Cycloclypeus*. Rutten (1927) gives the distribution of foraminifera in these Tertiary beds in much greater detail.

Umbgrove (1934) showed graphically the Tertiary history of this region. A table he gives is too complicated to reproduce here, but the following facts are transcribed from it.

In Borneo Tertiary rocks are shown in the Barito and West Pasir basins where the succession begins with Lower Eocene beds succeeded by Upper Eocene, Oligocene and Miocene marine beds, fluviatile beds coming again with the Pliocene : in East Borneo, Mangkalihat, there is a succession of marine beds from the base of the Eocene to the top of the Pliocene : in Beraoe there was land in Eocene times succeeded by marine beds in Oligocene and Lower Miocene, alternating with fluviatile beds in later times : in the "Tidoengsche Landen" there is a complete marine succession from the base of the Eocene to the top of the Pliocene.

In Sumatra ; at Kroei, S.W. Sumatra, there are marine Miocene and Pliocene beds : at Bencoolen Pliocene marine beds : in Acheen, North Sumatra, a complete succession of marine beds from the early Eocene to Pliocene except for fluviatile beds at the top of the latter : in South Sumatra the beds are marine Upper Miocene with some fluviatile in the topmost division and fluviatile Pliocene.

In Java there are marine Eocene beds in Djiwo succeeded by Upper Miocene, but part of the Miocene and the Pliocene were periods of no sedimentation : in Bantam and the south part of Bajah marine beds extend from the base of the Eocene to the base of the Upper Miocene, followed by marine Pliocene beds : in North Java are marine Miocene and Pliocene beds succeeded by fluviatile Pliocene beds : in the north part of Bajah marine Miocene beds are succeeded, after a period of no sedimentation in Upper Miocene times, by fluviatile Pliocene beds.

In Dutch New Guinea there are Eocene and Miocene marine beds, and in the north fluviatile Pliocene beds.

In Celebes marine Eocene, Miocene, and Pliocene are found in the east, marine Miocene and perhaps Pliocene in the central part: in the east part of South Celebes Lower Eocene fluviatile beds are succeeded by Upper Eocene, Oligocene, and Miocene marine beds with fluviatile beds in the Upper Miocene and Pliocene: in the west of South Celebes fluviatile Lower Eocene are succeeded by marine Oligocene and Miocene, followed by dry land conditions in the Upper Miocene and Pliocene.

Umbgrove gives details of several other islands which cannot be reproduced here with any useful result in the space available. In the transcript above the familiar European terminology has been used for convenience to the reader though Umbgrove gives the divisions quoted above with the "Tertiary without *Orbitoidea*" represented by two divisions "g" and "h".

Plate IV of Meinesz's work (1934) is a map of the Archipelago and Peninsula showing regional isostatic anomalies. On this map are marked regions that were above sea-level during the greater part of the Tertiary period. They are, the Peninsula, the east coast of Middle and South Sumatra, the Riouw and Lingga Archipelagoes, Banka, Billiton, and part of West Borneo.

There is a consensus of opinion among geologists in Malaysia that the Pleistocene glaciation had a great influence on variations in sea-level in that region. Daly's theory of glacial control of coral reefs is well-known, but the literature dealing with the effect of the alterations in sea-level in Malaysia is not so familiar. Fortunately there are papers written in English dealing with the subject, one being by J. H. F. Umbgrove (1929), in which the author summarizes previous literature and arrives at the conclusion that at the height of the glaciation the sea-level was approximately 100 metres lower than at present. This lowering of the sea led to the formation of Sundaland, now marked by the submarine Sunda Shelf, which has its counterpart on the other side of the Archipelago in the Sahul Shelf; but the amount of fall in sea-level assumed by Umbgrove does not meet with general acceptance In a paper by Ph. H. Kuenen (1933) the author discusses Umbgrove's figure and says:—

> "Molengraaf in his wonderful analysis of the features of the enormous shelf between the Soenda islands, pointed to various signs of a former lower sea level. The most striking phenomenon is the beautiful set of drowned river beds on the Soenda shelf. Whatever our belief is concerning the way in which this shelf was formed, it must be admitted that during the maximum lowering it was dry and traversed by gigantic rivers, carrying the water to various surrounding seas. . . . Umbgrove pointed out that the amount of drowning is probably slightly more than Molengraaf assumed (72 m.). Umbgrove showed that the drowned valleys attain depths of 90–100 metres at their mouths, and concluded that the glacial sea level was lowered to this extent. There are two objections to this reasoning. In the first place we cannot directly conclude what the sea level was from the depths of the valleys. Large rivers often attain great depths in their lower reaches. The Mahakam in East Borneo, for instance, is 50 metres deep far inland. . . . We could also

attempt to locate the Pleistocene coast-line and ascertain its depth. This cannot be done accurately. As far as I can see the charts indicate a depth of some 80 metres. . . . The second objection to Umbgrove's conclusion is that he assumes stability of the shelf since the drowning. It is true that the central part of the block containing the shelf with the larger Soenda islands is generally considered stable. This should only be taken to mean that it is stable compared with the tectonically active regions along its margins and to the east. Absolute stability is not implied. . . . A comparison of Daly's conclusion of the glacial level from rimless banks with our result of 80 metres indicates a probable sinking of the Soenda shelf of about 10 or 20 metres. . . . In my opinion too little is as yet known of what actually took place during the glacial period to allow a definite conclusion to be drawn. Umbgrove is, nevertheless, right in pointing out that the *relative* sinking of the Soenda shelf is more than was formerly assumed. Daly has also increased his estimate of the lowering of sea level to 90 metres (in my opinion on not quite sufficient grounds)."

It is, however, generally accepted that there was sufficient lowering of sea-level to unite Sumatra, Borneo, and Java to the mainland of Asia. There is evidence also that when the ice began to melt again after the maximum glaciation the sea-level rose ultimately to a higher level than at the present day and then fell again. The great rivers of Sundaland must have deposited thick beds of alluvium, but, as Van Es has pointed out (1929) it is very difficult to distinguish the strata that precede or succeed the rising of the ocean, so there is no basis for a true comparison of Pleistocene beds of Europe and Java. In the Peninsula, however, there are high-level alluvial beds in Perak, the Gopeng Beds, and in Singapore Island, the former marking old deposits of the Kinta River or a tributary, the latter old deposits of the Johore River, that can with some confidence be referred to this period. Some years ago a glacial origin was claimed by the writer for the Gopeng Beds, at a time when they were thought to be older than the tin-bearing granite of Kinta, but that view was discarded when it was proved beyond doubt that they were younger. The question still remains if there was any marked difference in climate when Sundaland existed compared with the climate to-day. The occurrence of large boulders in clay might be adduced in favour of the Gopeng Beds, which, it may be remarked in passing, are very like the so-called breccias of Permian age between Dawlish and Teignmouth, being glacial, but this mixture may also have been caused by sinking of clay and boulder-beds over a dissolving limestone surface, and it is therefore impossible to assume that there was a marked difference in climate in these latitudes during Pleistocene times without good palaeontological evidence. In Verbeek's *Commemoration Book*, Roy Dickerson contributed a paper that is useful in this connection (1925, pp. 111–119). Dickerson concludes that on the evidence of mollusca the climate of the

Philippines has altered but very little during late Tertiary, Pleistocene, and Recent times. He quotes J. Schuster, however, on the fossil flora associated with *Pithecanthropus erectus* at Trinil and his conclusion that there was in Java a more temperate and rainier climate than exists at the present time ; but on the other hand he quotes Merrill as saying that Schuster's general results were unwarranted and that

> " making due allowances for possible errors in identifications, I can see no reason for believing that the fossil flora of the *Pithecanthropus* horizon represents other than elements from a single forest type, that is a tropical forest very similar to that occurring at low altitudes to-day in the entire Malay Archipelago."

Dickerson said :—

> " The evidence in hand indicates that the direct effects of the glacial chill of the Pleistocene were almost entirely damped in the Philippines and East Indies, although it is recognized that the equatorial African Mainland was considerably colder."

In New Guinea there is good evidence that the snowcapped mountains are but a remnant of a much more extensive glaciation, and this contrast with equatorial Africa is not convincing. Dickerson gives the heights of Kenya and Kilimanjaro as 17,040 ft. and 19,456 ft. respectively. Rutten gives the heights of Wilhelmina and Carstenz in New Guinea as 4,750 m. and about 4,800 m. or 15,580 ft. and 15,744 ft. respectively. On Kenya traces of glaciation are found 5,400 ft. below the present glaciers, and until we know how far below the summits in New Guinea traces of glaciation are found we cannot say which country was the colder in the Pleistocene. On the other hand, if glaciation on Wilhelmina extended downward for 5,400 ft. from the present summit, its limit would have been at 10,180 ft., which is considerably lower than Kinabalu in British North Borneo, 13,455 ft., and no one has yet detected any trace of glaciation on that mountain. It seems that whatever the evidence of fauna and flora may be, the climate must have been somewhat cooler in Pleistocene times if extensive glaciation existed in New Guinea (see Brouwer, 1925, p. 39), and that Schuster was right as far as temperature was concerned ; but there is no reason to suppose that in the Peninsula the Pleistocene climate dropped so low that glacial deposits could be expected on the highest mountains of the present day.

THE IGNEOUS ROCKS

The following is a list of the chief igneous rocks found in Malaysia (Brouwer, 1925, p. 40) :—

> Granitic to dioritic rocks, gabbros to peridtites, foyaitic to theralitic rocks, rhyolites, quartz-porphyries, trachytes and porphyries, dacites and quartz-

porphyrites, andesites, keratophyres, alkali rhyolites, alkali trachytes, trachy-andesites, basalts, melaphyres, picrites ; serpentine and diabase ; phonolites, leucite and nepheline rocks, trachy-dolerites, tephrites, basanites, melilite-basalts, limburgites and augitites.

He says that the alkali rocks have a very limited distribution.

There are many attractive subjects for petrological research among the igneous rocks of Malaysia, and also among the metamorphic rocks such as the tourmaline-corundum rocks that are believed to be metamorphosed bauxite. For instance, J. A. Richardson (1939) has recently described what he considers a marked case of hybridism between ultra-basic rocks and granite in Pahang. In the islands between Singapore and Johore again, and on Singapore Island itself there are volcanic, plutonic, and hypabyssal rocks including lamprophyres that have been partially described (Scrivenor, 1931, pp. 38–48), but await more detailed study, and much remains to be learned about the enormous batholith of granite and allied rocks that forms the basis of the Peninsula ; but here space permits of only two subjects being briefly discussed, one the distribution in time of the volcanic rocks of Malaysia, the other the dates of intrusion of granite and allied plutonic rocks, without attempting to enter into petrological detail in either case.

The Malay Archipelago is famous as the scene of intense volcanic activity at the present day, Java being well known as an island where, thanks to the highly developed road-system, volcanoes can be viewed with such ease that in one case (Tangkoeban Prau) motor cars can be driven to the rim of the crater. It is difficult to imagine any island of the same size as Java, which is approximately the same in area as England, more volcanic ; but nevertheless the volcanoes of Java, Sumatra, and the other islands of the volcanic arc are but a remnant of far wider-spread vulcanicity in the past, beginning, as far as the record is known now, with the Carboniferous period. In the Peninsula the rocks that bear testimony to this Palaeozoic vulcanicity are called the Pahang Volcanic Series, a name which has been retained because it has been adopted elsewhere. The series consists of tuffs, lavas, and hypabyssal rocks ranging in composition from rhyolites to andesites and basalts. They are not confined to the Carboniferous but occur with the Triassic rocks also. They are best developed in Pahang and Kelantan, but occur in other States as well. In Sumatra there is evidence of contemporaneous volcanic rocks and in Borneo the Trias and possibly Cretaceous have similar volcanic rocks associated with them, described by Wing Easton (1904) and others. E. S. Willbourn has described the Pahang Volcanic Series in some detail (1918 and 1925).

The only rocks of the Pahang Volcanic Series that need be mentioned here especially are boulder-beds exposed with tuffs on and near the Pahang River that were puzzling at first but are now known to be ancient " *lahars* " or mudstream boulder-deposits such as one can see round Gunong Keloet and elsewhere in Java. Reference to Brouwer (1925, pp. 41–4) will show that vulcanicity persisted through Jurassic and Cretaceous to Tertiary times. In Borneo andesites are found in the Sarawak goldfields of Bau and Bidi associated with the Jurassic rocks there exposed. In Mid-Java Ch. E. A. Harloff has mapped sheared quartz-porphyry believed to be of Mesozoic age south of Bandjarnegara (1933). The author refers to this rock as crystalline schist. The writer has seen these Mid-Java rocks as well as those in Sarawak. There is nothing in the Peninsula like the glassy andesites, some with hypersthene, of Sarawak ; but the sheared quartz-porphyry of Harloff's area is indistinguishable from much of the sheared quartz-porphyry found in the Peninsula.

The question of the dates of irruption of the granite and allied plutonic rocks of Malaysia is becoming clearer as the work of the Dutch geologists advances. There seems to be no doubt that some of the granite in Sumatra is Palaeozoic, and in Triassic conglomerate on Singapore Island and adjacent islands, such as Pulau Sambo, pebbles of granite and schorl-rock have been found that must be older than the rocks containing them and therefore than the granite intruded into the latter (see Scrivenor, 1931, pp. 49, 50, for further information about this Palaeozoic granite). There is no doubt, however, that the granite batholith of the Peninsula is at least younger than Trias, with the reservation that further work may show some of the granitic rocks to be younger than the main period of intrusion ; and in Sumatra there is good evidence that some of the granite is post-Valanginian, the base of the Swiss Cretaceous, which makes a late Cretaceous or Tertiary date for the intrusion of the Peninsular granite very probable, but in the absence of better palaeontological evidence in the Peninsula nothing more definite can be said. In recent years, however, the Dutch geologists have produced very important information about granitic masses that were intruded as late as Miocene times, which may lead to revision of views expressed about the igneous rocks of Singapore and neighbouring islands mentioned above. The first published reference to these late Tertiary granite intrusions was in a report for the third quarter of the year 1930, issued by the Mijnbouw. In this report the granite is described as occurring in the southern part of the Bencoolen District between West Semangko and the coast, and is therefore nearly at the extreme southern end of the west coast of Sumatra. It is associated with granodiorite, quartz-diorite and diorite and all are intrusive into the "old andesite formation" in which veins of dioritic rock are found. The granite and other plutonic rocks were thought to be younger than the surrounding volcanic rocks and younger than the folding of the older Neogene sediments. In 1933 (see Westervelt) a map of this area was published as part of the Geological Map of Sumatra, 1 : 200,000. The intrusive mass has greatest breadth 28 km. In the explanatory text it is stated that the old andesite formation forms the base of the young Neogene sediments along the coast and Westervelt says that it is inseparably bound to the old Neogene sediments which are intercalated with it. In the explanatory text of Sheet 2, J. Zwierzycki (1932) says that small masses of granite, grano- and gabbro-dioritic rocks with gabbro occur, also the old andesite formation, but he says that it cannot be proved in every case that the granitic rocks are intrusive and therefore younger. This sheet is immediately to the east of the Benkoenat sheet and includes part of the Sunda Straits. In West Java one map (Koolhoven, 1933) has been published showing outcrops of granodiorite and quartz-diorite with large outcrops of the old andesite formation, which on the map is stated to be young Eocene to old Miocene in age. The granodiorite is shown as Oligocene or even oldest Miocene. In the explanatory text the author says of the old andesite formation that it consists of a thick series of volcanic rocks with here and there intercalations (*schakelingen*) of young Eocene, Oligocene, and old Miocene sediments. Of the granodiorite he says that in the adjoining area to the west, Malingping, the total outcrop is about 12 square km. The outcrop of the Bajah sheet is smaller, but continuous with the other, and forms part of a laccolith intrusive into the old andesite. Dacite, marked on the map as Neogene, is said to be intrusive in the Eocene sediments. Koolhoven says that it is established that the old andesite round these granodiorite outcrops is intrusive into Eocene sediments. Quartz-diorite and diorite are intrusive into old Miocene rocks.

TECTONICS

The literature on the tectonics of the Malay Archipelago can perhaps with justice be described as profuse, but there are sources of general information on the subject that are very welcome to us in England. One is Brouwer's chapter on "The Major Tectonic Features" (1925, pp. 46–73), another

Umbgrove's " Short Survey of Theories on the Origin of the East Indian Archpelago " in vol. ii of *Gravity Expeditions at Sea*, which is followed by another chapter on the relation between submarine topography and gravity-field by Ph. H. Kuenen ; and yet another is Umbgrove's *Geological History of the East Indies* (1938). Mention should also be made of a lecture by Brouwer to the Geological Society of London (1938).

Umbgrove's chapter in *Gravity Expeditions at Sea* is a valuable summary of various views that have been expressed, no less than forty-two authors being mentioned, and also contains gentle criticism of the not very well-founded speculation that many have indulged in while trying to explain the " arcs " of this region. He reproduces many maps, thus illustrating the considerable divergence of views, and the following passages are worth quoting, names being omitted :—

> " in order to fix our ideas it may be useful to draw such lines across islands which, for some reason or other, one thinks belong together, and it goes without saying that different authors do not make identical suppositions concerning the same subject. We may therefore expect *a priori* that A's tectonic map looks different from B's, that C's picture is again different and that D has designed a picture which again differs from this latter, while E's geotectonic map has a different aspect from all the rest, and finally the same may be said of a map recently published by F."

Most of the maps show lines representing folds and passing from island to island in bold curves, especially in the eastern portion of the Archipelago, but two maps are also reproduced on which numerous faults are shown to explain the structure ; but in one case many of the faults are shown where there is nothing but sea-water, while of those that touch the land two are shown crossing the Peninsula that are entirely imaginary ; while of the other an authority is quoted as saying that it is the worst example of the craze for drawing lines that can be found in the literature about the East Indian Archipelago. Umbgrove very wisely begins his chapter with a quotation from Rutten in which the latter says that all geologists should direct their efforts towards obtaining much more complete knowledge of the Archipelago rather than indulging in attractive hypotheses. Brouwer spoke to much the same effect in his lecture.

The western part of the area, comprising the relatively stable Sundaland portion, does not present great difficulties. Umbgrove sums up well as follows (1938, p. 65). Proceeding from north-east to south-west we find a zone of folded pre-Tertiary rocks, then the geosynclinal basins of Acheen, and Central to Southern Sumatra, folded towards the end of the Pliocene, and the western strip of Sumatra with the islands off the coast whose most recent folding occurs in the Miocene. It is the eastern part of the Archipelago, with the deep Banda Sea, that causes so much speculation ; how to fit in the extraordinary shapes of Celebes and Halmaheira, the latter looking like the small brother of the former ; and how to decide whether Buru and Ceram are a continuation of the Bird's Head of New Guinea or part of a sharply curved arc that sweeps round east of Weber's Deep to the Tenimber Isles, Babar, Timor and Sumba, with a smaller interior arc on the west of Weber's Deep from the Banda Isles to Damar, Wetar, Flores, and on to Java ; and how does that sharp bend come about if it exists ? By far the most plausible hypothesis is Wegener's, who (see 1924 translation, pp. 67–70) suggests that originally the Sunda Islands and those of the Bismarck Archipelago formed an unbroken line and that Australia with New Guinea as a spear-head pierced this line and crumpled it up in the immediate neighbourhood of the Bird's Head of New Guinea, thus producing the sharp arc of the Banda Sea. Wegener points out two facts in support of his hypothesis : the outer row of islands, Sumba, Rotti, Timor, Tenimber, has been partially disorganized because it is nearest to the advancing mass of Australia while the inner row, Sumbawa, Flores, etc., retains its alignment ; and of the islands of the Bismarck Archipelago, one, New Britain, looks as though it had been dragged along by the advancing New Guinea from its position in the alignment. Several objections to Wegener's hypothesis have been raised by Gerth and Kuenen. For instance the latter points to the identity of the Mesozoic sediments of two parts of the Australian block, Misool and New Guinea, with those of Ceram and the Sula Islands as forming a link between the East Indies and Australia. The critical area lies between Borneo and New Guinea, and a glance at the map shows that region to be chiefly occupied by sea. If there were more land we might learn more.

Of the many tectonic maps that published by J. Zwierzycki (1929) on the scale 1 : 5,000,000, deserves special mention because of its comprehensiveness, though one cannot agree with all the lines he has drawn, nor is it clear why the overthrust sheets of Djambi, in Sumatra, should be considered the equivalent of the Pahang Volcanic Series ; but the value of the map lies in the fact that it gives a great deal of information graphically about folding at various times. In the English summary of the explanatory text, Zwierzycki says that after probable Palaeozoic folding, preserved in scattered, small exposures, the chief orogenic period was of Cretaceous age. He mentions the Valanginian in Sumatra as the youngest formation in those folds, and says that in West Borneo similar folds are covered unconformably by the Cenomanian, also that the folding was everywhere very pronounced and resulted in isoclinal folds and even in overthrusts in Sumatra and Java. Palaeogene folding was not so important, but in Miocene and also Pliocene times important folding took place. He says that the quaternary and recent movements are all of orogenic origin, and that we find everywhere on the islands coral reefs at different heights, indicating tilting and folding. Umbgrove (1938, pp. 50–5) discusses the earth-movements from late Pliocene onwards, and remarks on the difficulty of separating late Pliocene from Pleistocene deposits. He connects the Miocene granitic intrusions mentioned above with either the Miocene period of folding or with the later " geanticlinal upwarping " of West Sumatra and South Java.

It is now generally accepted that mountain-building movements are in progress at the present time. A quotation from Brouwer must suffice here on this subject (1923, pp. 57 *et alia*) :

> " Though it is often difficult to identify the trend-lines of the older stages of mountain-building, the main trend-lines of the most recent movements are clearly evidenced because of the uplifts of the land relative to the sea. The youngest movements are restricted mainly to the eastern part of the Archipelago and to those parts of the western islands which border on the Indian Ocean. In these areas the surface expression of the lithosphere is controlled, not by erosion, but by the mountain-building processes which are in operation at greater depths. . . . The arcs about the Banda Sea have already been referred to as representing the embryonic stage of a folded mountain range."

Brouwer then describes vertical, horizontal, and oblique movements in this mountain-building, and on pp. 64, 65 ends with the following :—

> " Whether the forces producing the horizontal movements are directed from the north-west as would follow according to the conception of Hobbs, or whether they come from the south-east, as Wegener would have us believe, cannot be determined from the data at present available."

Regarding the anomalies of gravity found by Vening Meinesz, the belts of negative anomalies extend along the south of Java and then along Timor, the Tenimber Isles, and on to the Weber Deep ; and again north of Sula to the south of Mindanao. These belts do not coincide with the deepest troughs exactly, nor do the fields of greatest positive anomalies coincide with the shallowest water, indeed on p. 193 (1933) Kuenen says that there is not an absolute coincidence between morphology and gravimetry, but nevertheless he feels he can draw the conclusion from these new data that Asia and Australia touch along a mobile belt, but belong to one continuous mass like Asia and southern British India, and that the deep basins and troughs are not the remains of a former oceanic connection between the Indian and Pacific Oceans.

VULCANOLOGY

It is impossible to deal with every branch of geological research in Malaysia in this short paper, but a subject that cannot be omitted is the work done by the Vulcanological and Seismological Survey under the leadership of C. E. Stehn with particular reference to the volcanoes Krakatoa, Merapi, and Keloet. Apart from this work a recent paper by R. W. van Bemmelen (1939) deserves mention. Toba is a lake of about 2,000 square kilometres with a large island, Samosir, in the middle of it. It lies in a deep trough and Van Bemmelen shows that its history is that of a volcano that first emitted andesite but later rhyolite during a terrific outburst which resulted in collapse and the formation of a caldera in which the lake is now situated. Rhyolite-ash from this main eruption covers between 20,000 and 30,000 square kms. in Sumatra and is also found on the Peninsula. Van Bemmelen mentions the discovery of hand-axes of Middle Pleistocene age under these ashes, and thus dates the main Toba-paroxysm as younger Pleistocene. The island Samosir and the peninsula that juts out into the lake between Prapat and Porsea are tilted blocks of the collapsed roof of the magma-chamber, which were pressed upwards after the main paroxysm. Unfortunately a statement is made in this paper that minute bodies found in the ash on the Peninsula and described as marine sponge-spicules (Scrivenor, 1930) are small glassy fragments of ash like Pelee's hairs, but the refractive index of the bodies is distinct from that of the ash. K. P. Oakley (1940) questions the determination of these minute bodies as sponge-spicules, but no other satisfactory solution of their origin has been reached.

The history of Krakatoa has been very thoroughly investigated by Dutch geologists, and the new eruptions that started in December, 1927, and are raising a new island, Anak Krakatoa, are being closely observed. The volcano began as an andesitic cone long ago. Tridymite-andesite can still be seen that formed part of this cone, which collapsed. Then a basalt volcano of smaller size rose from the sea. Later two andesitic cones rose to the north and formed one island with the basalt volcano.

In the great eruption of 1883 it was these northern cones, Danan and Perbuatan, that were active, and the great explosion of the eruption was caused by their collapse into the sea, which resulted in masses of sea-water flashing into steam. There is still a general impression in England that in 1883 Krakatoa " blew up " but it did just the opposite, it collapsed to form, for the second time, a caldera.

The last paroxysmal eruption in Java was that of Merapi which occurred in December, 1930, and lasted well into 1931. This was the subject of a monograph by M. Neumann Van Padang and M. Hartmann (1933), which is beautifully illustrated. The eruption of 1930–31 was preceded by years of careful observation on the summit, and it is remarkable that it was not preceded by a general increase in the temperatures of the fumaroles there, which was disappointing because it was hoped that careful observation of temperatures on the active volcanoes, such as Papandayan, might enable the staff to warn inhabitants in the vicinity of a coming eruption. Merapi is also remarkable for the emission of clouds of hot gas and incandescent ash, named by the Dutch *gloedwolken* or fire-clouds. They were first observed on Merapi in 1920, and on account of the viscosity of the magma it was expected that such fire-clouds would be of small size, but the last eruption showed that Merapi could vie with Mount Pelee in this respect. These fire-clouds are called " *ladu* " by the Javanese, possibly because of some resemblance of the form of the cloud to a certain kind of sugared cake. The largest fire-cloud of the 1930–31 eruption burst out on 18th December, 1930, and reached a distance of 12 km. Twenty sq. km. of country were devastated with the loss of 1,369 human lives and about 2,100 animals.

Keloet (pronounced " K'loot ") is a comparatively inconspicuous volcano near Kediri, but has a very bad reputation owing to the fact that it ejects a crater-lake when it erupts, forming hot mudstreams laden with boulders and sand by which enormous damage has been caused. The last eruption took place in 1919, when 38,000,000 cu. m. of water were ejected, and reached a distance of 35 km. When the writer visited this district in 1929, it was noticed that some people had constructed small mounds of concrete or other hard material in their gardens so that if another mudstream came they could seek refuge on them. These mudstreams are called " *lahars* " locally, and the deposits left by them have, after denudation by rain, a resemblance to glacial deposits. On large boulders strewn on a plain where the finer material had been removed by rain, scratches were observed like faint glacial striae, caused by the collision of boulders as they were swept down from the volcano. In another place "perched blocks" were seen that looked like glacial erratics but were simply large boulders that streams could not remove when the finer material was washed away.

Keloet is also famous for the measures taken to lessen the danger from ejection of water in a future eruption by draining the crater lake. By a series of siphonings through tunnels dug in succession through the crater wall at increasingly lower levels the lake has been reduced to 5 per cent of its former volume. The works took nine years to complete.

In conclusion the writer wishes to express his appreciation of the friendly co-operation of the Dutch geologists over many years and of the valuable help he has received from them, and it is sincerely hoped that the temporary interruption of communications with those in Holland caused by war may soon be ended.

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CORRESPONDENCE

CORRELATION OF LAKI BEDS

Sir,—When defending his correlations (1939) which I have questioned (1940*b*), Mr. Pinfold (1940) apparently thinks that the Punjab contains nothing that I would regard as Shekhan Limestone; but I have shown (1940*a*) that I regard representatives of that limestone as extending to within a few miles of the Salt Range itself.

Again: when correlating the Nammal Shales of the Salt Range with the Ghazij Shales of Baluchistan, Mr. Pinfold overlooks the presence of basal Laki forms like *Nummulites lahirii* in the one and late Laki forms like *Assilina daviesi* in the other. Nor can I accept his generalizations about exposures of the "Dunghan" Limestone until I have seen adequate fossil evidence in their support.

The palaeontological facts are as follows:—

1. The earliest known Laki fauna appears in the Nammal Shales of the Salt Range. It includes numerous *Nummulites lahirii*, *Nummulites* cf. *kelatensis* and a variant of *Assilina dandotica*. Traces of this fauna have been seen in collections from the base of the Meting Limestone of Sind, but never at any higher level.

2. The next formation, or Sakesar Limestone of the Salt Range, like the Meting Limestone of Sind and its Baluchistan equivalent, abounds with *Alveolina globosa*, which thereafter seems to disappear.

3. Succeeding this limestone, on the Salt Range as in Baluchistan, come the first known, relatively rare, appearances of *Assilina daviesi*. The same form appears in the later Laki beds of Afghanistan (De Cizancourt, 1938). On the Salt Range this level is represented by the Bhadrar beds, which are definitely younger than the Sakesar Limestone and older than the Shekhan Limestone.

4. The latest Laki beds of Baluchistan, as of the northern Punjab (except the Salt Range) and Kohat, see the influx of numerous *Dictyoconus*-group forms, which survive far into the succeeding Khirthar. *Assilina daviesi* usually abounds at this level, as the characteristic—if not the only—assiline of the same. This is the Shekhan Limestone level.

When defending the term "Dunghan" Limestone, Mr. Pinfold claims the suffrage of most geologists who, he says, know "that formation". But very few geologists have visited Dunghan Hill, and none have figured Eocene fossils from it; indeed the Geological Survey of India formally referred the Dunghan Limestone to the Cretaceous (Holland and Tipper, 1913–16). As I have already pointed out (1940*b*), all the "Dunghan" fossils cited by Pinfold himself were actually obtained from the Bolan area. Hence my preference for the term "Bolan" Limestone.

I understand that collections from Dunghan Hill have recently been made by the Burmah Oil Company. If adequately figured and described, these should show whether or not an equivalent of the Bolan formation is to be seen there.

Mr. Pinfold apparently accepts my contention that, contrary to general opinion, Ranikot beds do exist in Baluchistan.

L. M. Davies.

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REVIEW

The Origin of Submarine Canyons. A Critical Review of Hypotheses: by Douglas Johnson. Columbia University Press, New York, 1939.

Within the last ten years echo-sounding and improved methods of fixing positions on the continental shelf and the slope beyond have made known the existence of a large number of submarine canyons, in addition to the Hudson and Congo canyons and the Fosse du Cap Breton which were already known.

The new methods have also enabled the form of these features to be determined with considerable precision.

The result of the discovery of the first group of these canyons near the Georges Bank, near Nantucket, was to stimulate theories to account for their formation. Some of these made such large demands on credulity that geographers and geologists felt they could not be accepted so long as there was a remote chance that some less fantastic explanation could be discovered. This challenge to inventiveness has resulted in such a large crop of hypotheses that the canyons have almost given pride of place as marvels to the ingenuity of the human mind.

Douglas Johnson (*The Origin of Submarine Canyons—A Critical Review of Hypotheses*) has performed a valuable service in subjecting these hypotheses to critical analysis and in bringing together references to the extensive literature which has gathered around them. As with others who have looked into these hypotheses carefully, he finds them inadequate or impossible and sets up a new hypothesis of his own.

About a dozen attempts at explaining submarine canyons are reviewed. They are classified broadly into: A. Hypotheses of a tectonic origin, and B. Hypotheses of a non-tectonic origin.

When only a few examples of these canyons were known, there was a possibility that they might be due to local faulting or folding. The great increase in their number during the last ten years combined with more accurate data of their plan and cross sections, makes it impossible to entertain such an explanation, and Johnson dismisses all tectonic theories in a few words.

The remaining hypotheses fall into three groups, viz.: Hypotheses of subaerial origin, hypotheses of submarine origin, and hypotheses of subterranean origin.

The subaerial theory exists in several forms; one attributes the canyons to river erosion when the continental shelf and slope down to some 10,000 feet were above sea-level in some recent geological period and subsequent drowning when the sea was restored to its present level.

Another regards them as features eroded in the solid rocks in the continental shelf at remote periods, perhaps even in the Palaeozoic. The canyons so eroded have subsequently been filled either partly or wholly with sediment, but have been in part or entirely emptied by landslides and subsequently maintained in their present form by submarine mud flows.

The recent geophysical evidence that the continental shelf south of Long Island is underlain by the seaward continuation of the coastal plain deposits of New Jersey, Maryland, and Virginia sets a limit to the remoteness of the period of cutting of the canyons, since the oldest of these is Cretaceous.

This modification of the subaerial hypothesis is due to F. P. Shepard and "apparently has been in part if not wholly abandoned by its author".

The canyons on the continental shelf of the Eastern United States of America do not in general occur opposite the mouths of great rivers draining the continent. This has prompted another modification of the subaerial theory, that the canyons are due to headward erosion of springs fed by ground water during a period of emergence.

With regard to the basic assumption of the enormous vertical changes of sea-level both down and up, Johnson remarks that there is apparently no independent evidence on the coastal borders of the land to confirm these up and down movements.

Nevertheless, the series of charts recently issued by the Geological Society of America accompanying Special Paper No. 7 have been contoured on the hypothesis that the canyons and the continental slope have been eroded under subaerial conditions. Incidentally, in Johnson's pl. iii, facing p. 18, where a portion of one of the charts of the Georges Bank area is reproduced the Lydonia canyon is misnamed the Oceanographer, the latter being in fact the unnamed canyon on the left of the plate.

Under hypotheses of submarine origin the possible roles of submarine landslides and submarine currents are examined.

The author's views on submarine landslides are considered more fully below.

Among the various submarine effects that have been appealed to, Daly's turbidity currents has received most notice in this book. This hypothesis is based on the assumption that water which contains much mud in suspension sinks in clear water and in doing so has sufficient energy to erode the surface over which it moves. This mud, according to Daly, was derived from the beating of the waves on the continental shelf while that area emerged as the result of the locking-up of water on land in the form of ice during the glacial period. The amount of emergence claimed by Daly is about 300 feet. The idea that such turbidity currents are capable of accomplishing erosion was entertained by Daly because ravines exist on the floor of Lakes Geneva and Constance in both of which waters heavily laden with silt and mud sink violently below the clear waters of these lakes. Daly relied on the authority of Forel that these trenches had been eroded, as de Salis believed, by the bottom current of turbid water.

Johnson in a review of views which have been held by various authorities regarding the origin of the sublacustrine ravines shows that far from agreeing with de Salis that they were due to erosion Forel regarded them as the products of deposition. Since these appear to be the only cases which have been claimed in support of the notion that turbid currents can erode considerable trenches this correction is of particular significance. Apart, therefore, from the innumerable difficulties in explaining how these turbidity currents could be localized at a few places on the continental slope the greatest obstacle to its acceptance is that there is no direct evidence that turbidity currents, even if they existed, could do the job.

Inasmuch as Daly's hypothesis was put forward in an attempt to discover some explanation less incredible than the erosion of the canyons by subaerial agencies, so Johnson concludes his review of it by saying: "having failed to discover a wholly convincing explanation in submarine and subaerial processes, we turn to the remaining realm, the subterranean region."

Suggestions have been made in particular by Milne and Benest that some canyons were eroded by subterranean rivers which emerged under the sea. Johnson remarks that this hypothesis is advanced in a tentative and very generalized form, and that it frequently tends to infer the existence of subterranean rivers where artesian conditions are found. On another page, however, the author uses the same argument in support of his hypothesis of submarine springs. "Where such deep wells [artesian] continue to flow indefinitely without becoming salt, there is indicated a continuous seaward movement of land water through aquifers leading to exits some distance farther out" (p. 75). Or again, " the fact that fresh water continues to flow from deep wells at the coast indicates that artesian waters at the depths tapped are flowing ever seaward " (p. 87).

Other hypotheses of canyon formation by foundering of subterranean caverns produced by solution along faults or prevention of deposition along faults owing to uprising subterranean waters are obviously inadequate to account for canyons in general, and were in fact all put forward in an attempt to explain the Fosse du Cap Breton.

The author then propounds his own hypothesis of " submarine spring sapping ". The springs are supposed to be fed " by waters, chiefly artesian, migrating through the sediments of the continental shelf to appear on its steeper seaward face ". He draws a distinction between these submarine springs and subterranean rivers, and appears to imply that the latter are inadequate to reproduce the features of canyons. In this respect he does scant justice to the idea, for if, as he claims, great results can follow from the action of springs one might at least infer greater effects from the much larger body of water in a river. Perhaps, however, he is tilting at the idea that such rivers excavated the canyons by direct erosion in the same manner as subaerial streams, though most of the views expressed on the process imply only that landslides and cave-ins have resulted from the excessive flow of water from submarine outlets. The difference between these views and Johnson's own hypothesis are not obvious.

This hypothesis implies that certain aquifers may lead rain water from the continental area under the continental shelf to the continental slope where it breaks out in the form of submarine springs.

Since all rock-forming minerals are more or less soluble in water, these springs cause solution and disintegration of the rocks around the point of issue. Much of the material may be carried away in solution thus eroding a channel, but if there is accumulation of debris falling in from the head and sides or by normal deposition on the slope, this may be removed by recurrent sliding of the mud on the floor and sides. The action of the spring water would tend to keep this mud in a fluid condition so that it flowed out readily.

This hypothesis by its appeal to direct solution of the material compares the formation of submarine canyons to some of the " box canyons " in the basalt area of the western United States and to certain valleys called " square heads " in Florida which are believed to be due essentially to that process. If the process is effective then obviously given sufficient time and a continued flow of artesian water there is no limit to the length of canyon which can be developed and the hardness of the rock in the walls is not a deterrent to their formation.

So far as the canyons off the eastern coast of the United States are concerned, Johnson believes that the artesian waters are conveyed from the Cretaceous-Tertiary coastal plain deposits under the continental shelf to the outer edge on the continental slope where they may issue at depths of 10,000 feet more or less.

Conditions in that area are not as favourable at present as they were in past times when Cretaceous and probably Tertiary rocks extended farther west over the continent and attained much higher levels. With regard to the Georges Bank canyons where no coastal plain deposits now remain it is suggested that as there are relics of Cretaceous and Tertiary rocks on Long Island and Martha's Vineyard they may once have existed to the north of the Georges Bank off the coast of Massachusetts. This implies that the formation of these canyons may have been accomplished mainly at some former period.

The outer face of the continental slope is probably covered in most cases by modern deposits of mud which would tend to blanket Cretaceous or Tertiary aquifers. It is suggested, however, that the submarine fresh water may have softened these to such an extent that the water broke through to the surface or alternatively that the mud has slumped off the slope and thus exposed these water-bearing horizons.

The author's views on the role played by mud flowing or slumping appear to be somewhat inconsistent. He devotes a section to an examination of the evidence which has been advanced by various authors that slumping occurs on the sea floor. This relates mainly to cable fractures either in association with seismic activity or independently and the burial of the cable under mud. He concludes that " in no instance can cable breaks as yet be definitely correlated with the sliding or flowing of debris accumulated as fill in older submarine valleys " (p. 12). He is here combating a particular mode of origin of canyons as older valleys subsequently filled with sediment and emptied by mud flowing.

On a later page, however, he writes, " that silts and clays on the seaward face of a shelf are especially liable to slumping and sliding even when fairly well consolidated ; that such slumping and sliding *has repeatedly been inferred as a potent cause of cable breaks* " (p. 87). [Italics are mine.]

His view appears to be that while slumping may take place on the seaward face of the continental shelf, it cannot account for canyons which he describes as " deep winding gorges " [which they are not].

Assuming that rain water from the land area can reach the outer edge of the continental shelf and then break out as springs, Johnson's theory assumes that these submarine springs are capable of excavating a submarine canyon the length of which depends only on the time during which it has been developed and the nature of the materials in its walls.

It is implied also that springs may be fed from connate water released fom the sediments during consolidation. It is well known that muddy deposits contain a large volume of water entangled in them, but that later the muds become firmer as this water is discharged. It is doubtful, however, whether the rate of loss of water could ever be rapid enough to promote a continuous flow. Further, under marine conditions the process of consolidation is very different from that in a river delta and is relatively more rapid. (See O. T. Jones, " The Consolidation of Muddy Sediments," *Geol. Mag.* lxxvi, 1939, 170, for reference to detailed treatment of this problem.)

The role attributed to these submarine springs is primarily that of solution of the rocks around the point of issue, with the possibility of some abrasion. It is suggested that as compared with land conditions owing to the somewhat higher temperatures and much higher pressures that prevail at the depths where they issue, the relative importance of abrasion and solution may be reversed.

The process is described in the following paragraph : " In the absence of definite knowledge respecting the growth of the shelf in Cretaceous, Tertiary, and later times, we cannot picture with any certainty the history of the sapping process. But we can at least consider possibilities. When spring sapping first started it was presumably active at countless points along the margin of the shelf. But just as on land countless small surface streams contending for drainage area soon give place to a relatively few most-favoured streams at widely separated intervals, so at the shelf border countless springs contending for subterranean drainage should soon produce by sapping a limited number of canyons more widely spaced. After the lapse of sufficient time there should be found : a few canyons cut very far back where conditions were specially favourable ; more canyons of intermediate length which were successful for a considerable period, but ultimately lost drainage as the more successful canyons pushed farther back into the shelf; and a multitude of incipient canyons or ravines which were quickly outdistanced by their larger neighbours. The seaward face of the shelf would thus be ' furrowed ' with many parallel or nearly parallel ravines of variable depth, but also trenched at intervals by the canyons, some of moderate, a few of major dimensions. The shorter ravines might branch moderately, but ordinarily the branches would not diverge widely from the general trend of the continental slope. The larger canyons could develop important and widely divergent branches in case subterranean drainage from either side favoured, at least temporarily, a major development of lateral spring sapping" (pp. 102, 103).

Any "silt deposited on the canyon bottoms would then give rise to flows of the relatively fluid mud which would evacuate the canyons at intervals, possibly carrying with them any coarser material washed in from the upper surface of the shelf, discharged by suboceanic springs, or fallen from the canyon walls" (p. 104).

Two criticisms of this process naturally come to mind. Before reaching the continental slope from the intake area the artesian water during its slow passage through about 100 miles or more has been in contact with the rocks of the aquifer for a long period of time. It might be expected, therefore, that the water would have attained saturation point in the dissolved ingredients long before it reached the sea floor, and that no further solution could occur. The possible effect of sea water on such a saturated mineral solution is a problem for physical chemists, and until an answer can be found the validity of submarine spring sapping is open to question.

The slope of any aquifer is probably not much greater than that of the continental shelf, and a good deal less than that of the continental slope. One might expect that the floors of a canyon would have a somewhat similar slope to that of the aquifer which guides the headward development of the trench. They are in general much steeper, and this prevailing high slope of the canyon floors does not seem to receive a satisfactory explanation in Johnson's hypothesis.

It is impossible to do full justice in a short review to the closely reasoned arguments for and against the various hypotheses which are discussed in this book and it should be widely read. For a book of 126 pages including an index of 6 pages and a French résumé of over 7 pages, the price of 15*s*. 6*d*. is exceedingly high and puts the book out of reach of the majority of geologists and geographers. It contains abundant references to the literature which has gathered round these features, but owing to the form adopted in quoting authorities there is an immense amount of repetition of these references.

O. T. J.

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The Upper Oxford Clay at Purton, Wilts, and the Zones of the Lower Oxfordian

By W. J. ARKELL

I. INTRODUCTION

AT Messrs. Hills' brickyard, ½ mile north-north-west of Purton Station and about 4 miles north-west of Swindon, Wiltshire, a large pit in Upper Oxford Clay (Lower Oxfordian) is worked by modern methods to a depth of over 60 feet. Ammonites are for the most part preserved as white powdery or flaky impressions, as in the Jordan Cliff Clay at Weymouth, and their collection involves technical difficulty. For help with the collecting and measuring I am indebted to Messrs. C. W. and E. V. Wright, and for every facility at the pit to Mr. Hill.

The section provides an interesting comparison with the large pits described almost simultaneously by Dr. L. F. Spath and myself at Warboys, Huntingdonshire (Spath, 1939), and Woodham, Buckinghamshire (Arkell, 1939), and with work on the Dorset coast, not yet published (Arkell, 1941 ?). Before the Purton pit can be described it is necessary to harmonize the results obtained and the terminology used at the other two pits, and to clear up some matters of nomenclature.

Dr. Spath's paper was published on 25th April, 1939, and mine, although read and published in abstract on 25th May, 1938, did not appear in full until 26th May, 1939. Luckily, however, none of the new names in the two papers clash and no alterations are necessary on that account. On the other hand, a number of new varieties of *Cardioceras praecordatum* Douvillé and *C. scarburgense* (Young and Bird) named by Dr. Spath are invalidated by a monograph on the genera *Quenstedtoceras* and *Cardioceras* published in the previous year (V. Maire, 1938) and the zonal terminologies employed need harmonizing.

II. CARDIOCERAS PRAECORDATUM Douvillé and C. SCARBURGENSE (Young and Bird)

These two Cardioceratids are the commonest fossils at Purton and at Warboys. Both have been used as zonal indices. Sayn (1930, p. 228) and Maire (1938, p. 57) like previous authors accepted as types of *Cardioceras praecordatum* the fragments figured in Douvillé's monograph (1912*b*, p. 62, pl. iv, figs. 10–18).[1] Being of the same opinion, and considering these fragments inadequate as types and hardly identifiable, but for the most part capable of being matched with specimens which cannot be separated from typical *C. scarburgense* (Young and Bird, 1822), I placed *praecordatum* in the synonymy of *scarburgense* (Arkell, 1939, p. 157). Spath, however, although he equated the two species in 1933, now separates them and takes as holotype the small nucleus figured by Douvillé in a semi-popular article in *La Nature* published in the same year (Douvillé, 1912*a*, p. 246, text-fig. 7*b*). The date of the *La Nature* article is 9th March, 1912, but inquiries of three London libraries and the Bodleian, and of the Geological Society of France and the three most likely French professors, have failed to establish the date (even the month) of publication of Douvillé's monograph. However, in spite of the *a priori* improbability that Douvillé would have published the new name first in a semi-popular article, it seems likely that the monograph was held up until after the appearance of the article, for Douvillé gave the exact date of the article when referring to it in the monograph, and his remarks therein seem consistent with a change of genus from *Cardioceras* in the article to *Quenstedtoceras* in the monograph rather than *vice versa*. In his 1913 work he again used *Quenstedtoceras*.

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[1] Maire excluded figs. 10, 13, 17, 18, without stating how they were to be interpreted.

If the *La Nature* nucleus be accepted as holotype of *Cardioceras praecordatum*, as seems indicated, it is important to notice that the original figure is reduced by 0·8. This is shown by the fact that the specimen of *Quenstedtoceras brasili* figured beside it reappears natural size as pl. iv, fig. 3, of the monograph, where it is 1·25 times the diameter of the original figure.[1] Hence the holotype of *Cardioceras praecordatum* is about 16 mm. in diameter, and it is probably refigured, reversed, and the natural size, as pl. iv, fig. 13, of the monograph.[2]

Fixation of the type as the 1912*a* nucleus enables precision to be achieved in the interpretation of *Cardioceras praecordatum*. That nucleus is certainly distinguishable from *C. scarburgense* (Young and Bird, 1822) (holotype figured, Arkell, 1939, pl. x, figs. 1*a–c*). Comparison of specimens at progressively larger stages of growth shows that Douvillé's figures represent the form called var. *douvillei* Maire (1938, p. 60), which I raised to specific rank (1939, p. 157), designating as lectotype *C. praecordatum* Douvillé, 1913, pl. vii, fig. 7 (synonym var. *praemartini* Spath, 1939, p. 92). For instance, a specimen of intermediate size to be figured in the Weymouth Memoir (Arkell, 1941 ?, pl. iii, fig. 4) is identical with the figures of the holotype of *praecordatum*. This result is a happy one, for it legalizes and stabilizes Douvillé's own interpretation of his species, published only a year after first publication of the name and since followed in nearly all the literature. If modern rules and terms had been current in 1913 Douvillé would have designated the better and commoner of his " deux beaux représentants " as neotype, for the 1913 figures were published expressly to supersede those of the nucleus and fragments previously published. While Douvillé's own virtual selection is thus literally correct now that the type is fixed, it is desirable to follow it rather than to accept as typical the nondescript English form (" not in place ") figured as typical by Spath (1939, pl. vi, fig. 2), which is much more difficult to separate from *C. scarburgense*

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[1] Acceptance of the priority of the *La Nature* article involves raising *Q. brasili* to specific rank with priority over *Q. henrici* and *Q. praelamberti* Douvillé (1912*b*, pp. 55–7).

[2] Spath, in referring to the " confusion increased " by my failure in 1933 to notice the error in Douvillé's plate iv, figs. 21–3, omits to mention that I was the first to point it out (Arkell, 1936, p. 176). Douvillé's fig. 21 (perhaps the same specimen as Douvillé, 1912*a*, fig. 7*c*), is a form of the Cordatus Zone near to *Cardioceras costellatum* Buckman. Maire (1938, p. 60) still has not noticed the error.

(Young and Bird). I therefore regard as neotype *C. praecordatum* Douvillé, 1913, pl. vii, fig. 7, a neotype being necessary to show the characters which the holotype is too small to show.

The distinctions which Spath (1939, p. 90) adduces between *C. scarburgense* and *C. praecordatum* still apply, and with added force: " The latter species has more flexuous and more projected ribbing as well as more pronounced keel and, indeed, is altogether a more typical *Cardioceras*."

Of the eleven new varieties and one mutation named by Maire and Spath, many overlap. The following notes indicate the meanings of the names still held to be valid and those which fall in synonymy.

1. *Cardioceras* (*Scarburgiceras*) *scarburgense* (Young and Bird). Holotype figured by Arkell (1939, p. 156, pl. x, fig. 1). In practice, *C. praecordatum* var. *transitoria* Spath (1939, p. 92, pl. vi, figs. 5, 6) cannot be distinguished. It is identical with specimens I matched with the type when on loan from Whitby, as being closest to the true *scarburgense* of all the material from Woodham and Warboys pits.

1*a*. Var. *intermedia* Maire (1938, p. 58, pl. vi, fig. 6, now designated lectotype). Synonym var. *normandiana* Spath (1939, p. 90). Ribs number about thirty-two at 30 mm. instead of about twenty-four in the type form.

1*b*. Var. *crassa* Spath (1939, p. 90, pl. vii, fig. 12). Ribs number about twenty-one at 30 mm. and are coarser; coiling more involute.

2. *Cardioceras* (*Scarburgiceras*) *praecordatum* Douvillé. Holotype figured Douvillé (1912*a*, fig. 7*b* (× 0·8), and 1912*b*, pl. iv, fig. 13, natural size). Neotype figured Douvillé (1913, pl. vii, fig. 7). Synonyms var. *douvillei* Maire (1938, p. 60), and var. *praemartini* Spath (1939, p. 92).

2*a*. Var. *mixta* Maire (1938, p. 61, pl. vi, fig. 12). This seems to cover " mut β " of Spath (1939, p. 93, pl. vi, figs. 3, 9).

2*b*. Var. *stricta* Maire (1938, p. 58, pl. vi, figs. 7, 8; pl. vii, fig. 1). Lectotype pl. vi, fig. 7, now designated. Synonym var. *extremis* Spath (1939, p. 93), based on *C. praecordatum* Sayn (1930, pl. xxi, fig. 13). Ribs occasionally branch a second time before meeting the keel.

Maire also named a *C. praecordatum* var. *multicostata* (1939, p. 59, pl. vii, fig. 2) and a var. *bukowskii* (1939, p. 64, pl. vii, fig. 8), better regarded as a separate species. The latter was called a separate species by Maire in the explanation of his plate vii, and it provides a better name than the doubtfully identical Alaskan *C. martini* Reeside for the common *Scarburgiceras* of the Yorkshire Lower Calcareous Grit.

Douvillé's coarse-ribbed " beau représentant " (1913, pl. vii, fig. 6), which Maire (1938, p. 57) places in the synonymy of *C. praecordatum sensu stricto*, is believed to be the nucleus of a different species, perhaps *C. alphacordatum* Spath (1939, pl. vi, fig. 10). Maire's own figures from other French localities

(1938, pl. vi, figs. 3, 4) show varieties of *C. scarburgense*. Fig. 4 is var. *transitoria* Spath, fig. 3 is var. *crassa* Spath.

III. CORRELATION OF WOODHAM AND WARBOYS PITS

At first sight it seems that beds A and B at Woodham (the Mariae Clays) are equivalent to beds 1–3 at Warboys (Spath's Lower Mariae Zone). The impression is enhanced by the chance that the beds in both pits measure 29 feet in thickness. Moreover, as I had predicted (1939, p. 206), some of the ammonites peculiar to collections from Warboys and St. Ives, and absent from Woodham, have proved to come from strata higher than beds 1–3 (*Quenstedtoceras stibarum* Buckman sp., *Oekotraustes scaphitoides* Coquand sp., *Peltoceras* cf. *eugenii* Raspail sp., recorded from Spath's beds 4 and 5, Spath, 1939, pp. 86–7).

There are certain facts, however, which indicate that the bottom of Warboys pit does not reach down so far as the top of Woodham pit and that there is no overlap of the two sections. In particular, Spath states (p. 85) that the true *Cardioceras praecordatum* (= *douvillei* Maire = *praemartini* Spath) occurs throughout his beds 1–6; whereas among over 150 Cardiocerates so far collected at Woodham pit there is only a single example of this form, a limonitic cast not found in situ, possibly from the soil. Moreover, the abundance of *Creniceras renggeri* in the lowest 12 feet of beds A and B at Woodham and its absence from beds 1–3 at Warboys is remarkable, and is not adequately explained by the appearance of *C. renggeri* and *C. crenatum* through a range of 13 ft. 6 in. of strata in beds 7 and 8, some 50 feet higher up and above the range of *Q. mariae*. The association of *C. renggeri* with *Q. mariae* and *C. scarburgense* in Buckinghamshire, Yorkshire, Surrey, the Boulonnais, and farther afield, makes it probable that Mariae-Renggeri Beds exist also at Warboys but lie below the floor of the pit. The reappearance of *renggeri* with *crenatum* at a much higher level may be compared with a recent record from bed H 13 in Normandy, only a few feet below the Oolithe ferrugineuse (Mercier, 1936).

IV. THE SUCCESSION AT PURTON BRICKYARD

Zonal collecting at Purton pit is rendered more difficult than at Warboys or Woodham, not only by the inferior preservation of the ammonites, but also by the absence of stone bands. The main mass of the section consists of 60 feet of unbroken clays, most of it exposed on a steep face. Consequently the sequence was measured off arbitrarily from the floor of the pit (in May, 1939) into six beds, each with a thickness of 10 feet. This arrangement has the advantage that the top of bed 3 coincides with the main platform in the middle of the section, and that the tops of beds 1 and 5 correspond with important changes of fauna. Even in the driest part of the summer, in June, 1939, the base-level stood under 6 feet of water. In May, 1940, beds 1 and 2 were submerged.

Purton pit does not overlap Woodham, but shows the same zones as Warboys, plus an interesting development of the Cordatus Zone, in the facies of the Red Nodule Beds of Dorset.

The following notes describe the ammonite succession traced through the six beds, from the base upwards.

Bed 1 (0–10 feet).—From water level to 10 feet above datum were 4 feet of clay, the lower part crowded with *Peltoceras arduennense* (d'Orbigny), *P. choffati* de Loriol, *P.* cf. *gerberi* Prieser, and occasional *Cardioceras praecordatum* Douvillé and *Quenstedtoceras* aff. *mariae* (d'Orbigny). Also *Hibolites hastatus* and crinoid ossicles.

Bed 2 (10–20 feet).—Abundant *Cardioceras praecordatum* Douvillé. Crushed *Grossouvria* sp. Many *Gryphaea dilatata* and *Hibolites hastatus.*

Bed 3 (20–30 feet).—No change in the fauna, but ammonites less common. At 2 feet from top a giant spinous *Aspidoceras* in fragments (? *loricatum* Bean MS., Spath).

Bed 4 (30–40 feet).—Cardiocerates very abundant, belonging to species characteristic of the Ball Beds at the top of the Scarborough Lower Calcareous Grit, though for the most part unnamed. Most characteristic are *C. bukowskii* Maire (= *C. martini* var. *anglica* Spath), *C.* (*Vertebriceras*) sp. nov., *C. anacanthum* Buckman, and *C. svelta* Maire (synonym *C. suessiforme* Spath) (all found at Scarborough). All these forms will be figured in my monograph on Corallian Ammonites.

Bed 5 (40–50 feet).—Some of the same Cardiocerates but less common. *C. bukowskii* ranges up at least to within 2 feet of the lowest band of red nodules. *Gryphaea dilatata.* Three black streaks in beds 4 and 5 do not keep to bedding planes and seem to be of tectonic origin.

Bed 6 (50–65 feet).—Red Nodule Beds. Pale grey clays with lines of red and grey kidneystones, some containing well-preserved (uncrushed) casts as at Weymouth. *Cardioceras costicardia* Buckman, *C.* (*Vertebriceras*) *quadrarium* Buckman, *Peltoceras* (*Peltoceratoides*) *constantii* (d'Orb.), *P.* (*Parawedekindia*) *schlosseri* Prieser.

There are at least 100 feet of Oxford Clay above the highest bed seen in the pit and below the Lower Calcareous Grit which crops out in the neighbouring escarpment at Paven Hill, unless there is a fault in between. No exposures have been seen in these beds. The clay changes to loam at about the base of the big landslip at the N.E. extremity of Paven Hill and there follow about 60 feet of loams and loamy sands before the Coral Rag is reached. The position of the brick pit in relation to the geology of the district is shown in Arkell 1941*a*.

The chief point of interest in this section is the presence of the characteristic *Cardioceras* fauna of the Ball Beds of the Scarborough Lower Calcareous Grit (beds 4 and 5), underlying the Red Nodule Beds of Weymouth (bed 6), with their characteristic fauna. For the first time these two faunas are seen in a single section and their order of succession is established.

Bed 6 of Purton is represented by a non-sequence above bed 8 at Warboys (Spath, 1939, p. 89). Beds 4 and 5 of Purton (20 feet) presumably correspond approximately with bed 8 at Warboys (23 feet), but the local distribution of ammonites at Warboys (Spath, 1939, p. 84) is not recognizable at Purton. Beds 1 to 3 of Purton (30 feet) may be assumed to be the equivalents of approximately beds 4 to 6 at Warboys (21 ft. 6 in.). Beds 1 to 5 at Purton are represented in Dorset by part of the Jordan Cliff and Furzedown Clays.

V. ZONAL SEQUENCE AND TERMINOLOGY

One of the unequivocal results of recent studies on the Oxford Clay of Dorset, Oxford, and Woodham Pit has been to establish the distinctness of the Lamberti and Mariae Zones. "The most satisfactory palaeontological line of separation between the Callovian and Oxfordian would be between the Lamberti and Mariae Zones" (Arkell, 1939, p. 213). Hence the Mariae Zone cannot be considered a subzone of the Lamberti Zone (Spath, 1939, p. 84).

The characteristic fauna of the Mariae Zone is *Q. mariae* (d'Orb.), *Q. omphaloides* (Sowerby), *Cardioceras scarburgense* (Young and Bird), *Creniceras renggeri* (Oppel), and *Taramelliceras richei* (de Loriol). This fauna is especially abundant and typical in the lowest 29 feet of the Mariae Zone as exposed at Woodham, and there *C. praecordatum* does not occur. At Warboys Spath describes another 29 feet of Mariae beds (1–3) in which *C. scarburgense* and *C. praecordatum* occur together; and since his var. *transitoria* is shown to range throughout his beds 4 to 6 (Spath, 1939, p. 84) a further 21 ft. 6 in. must be included in the beds with both *scarburgense* and *praecordatum*. At Warboys Spath does not mention any beds characterized by *Cardioceras praecordatum* alone, but 30 feet of such beds (without *C. scarburgense*) are seen at Purton (beds 1 to 3), and these are higher than at least beds 1 to 3 at Warboys. This is the Praecordatum Zone of de Grossouvre, Buckman, and Morley Davies.

The Mariae Zone may therefore be divided into three subzones: a lower subzone with *C. scarburgense* (Woodham); a middle with *scarburgense* and *praecordatum* (Warboys); and an upper with *C. praecordatum* only (Purton); the thickness of each subzone being at least 30 feet.

At about the junction of beds 3 and 4 at Purton there is an important change of fauna. The subgenus *Scarburgiceras* continues to be represented, but by a form with ribs that are still finer than those of *praecordatum*, and projected more acutely at the ventral margin, to form a completely differentiated keel. This is a species that abounds in the Ball Beds at the top of the Lower Calcareous Grit of Scarborough. The correct name for it appears to be *C.* (*S.*) *bukowskii* Maire (synonym *C. martini* var. *anglica* Spath). Some specimens are much larger than others, and more than one species may be represented. With this form comes in an abundance of Cardiocerates of other subgenera, not previously represented, but all characteristic of the Scarborough Ball Beds. Here for the first time appear strong tuberculate primary ribs, square shoulders, and flat venters; but not yet, apparently, large smooth body-chambers. None of the forms seems to exceed about 3 or 4 inches in diameter. Among them are early *Cardioceras sensu stricto* and an unnamed *Vertebriceras*, characteristic of Scarborough.

Of these forms *C. bukowskii* is recorded from beds 7 and 8 at Warboys, and *C. svelta* Maire (= *suessiforme* Spath) from bed 8. These two highest beds (7 and 8, 30 feet) Spath calls the subzone of *C. martini* var. *anglica* (= *bukowskii*) and *C. praecordatum* mut β (? synonym of var. *mixta* Maire), and he assigns it to the Cordatus Zone *sensu lato*. At Purton and at Scarborough there is no " mut β ", from which it may perhaps be inferred that most of the Warboys beds 7 and 8 are rather lower than the Purton beds 4 and 5 : perhaps an earlier part of the same subzone. It is now proposed to call the Purton and Scarborough beds the Bukowskii Subzone of the Cordatus Zone.

Finally with bed 6 there enters a third fauna of Cardiocerates, accompanied by some large Peltocerates. This fauna has been listed by me on several previous occasions as characteristic of the Red Nodule Beds of Weymouth, the Oolithe ferrugineuse of Normandy, the Studley Clay near Oxford, and the Lower Elsworth Series of Cambridgeshire. The species are all distinct from those in the Ball Beds, except *Goliathiceras goliathum* (d'Orbigny), which occurs in both. Some of the Cardiocerates, however, occur in the Hambleton Oolite Series (especially the Passage Beds) of the Yorkshire Coast, which are the home also of the large Peltocerates, *P.* (*Peltoceratoides*) *williamsoni* (Phillips), *P. constantii* (d'Orb.), *P. hoplophorus* Buckman, and others. This is the Cordatus Zone par excellence of d'Orbigny and other writers, which Spath (1939, p. 84, and earlier papers) calls the Cardia Zone or Cardia Subzone. There are two objections to this name, however. In the first place, if it is thought necessary to use a different name for the index fossil owing to a divergent interpretation of *C. cordatum*, Buckman's *cardia* will not do, because it is a synonym of *Cardioceras subcordatum* Pavlow (1913, p. 48).[1] In the second place, and more serious, the true *C. cordatum* (J. Sowerby's, fig. 4) (= *subcordatum*, = *cardia*) does not occur in this fauna. It has been found in England probably at only two localities, in the Lower Calcareous Grit of the Seend district, Wiltshire,[2] and the Lower Calcareous Grit of the Birdsall and Malton district of Yorkshire. In both places it is associated with a fauna of other Cardiocerates closely allied to it but not found in the Red Nodule Beds assemblage : fairly large *Cardioceras sensu stricto* with smooth body-chambers. The position of this fauna relative to the others has not been proved by direct observation, but it may be inferred to be later, and it might be expected in the lower parts of the Nothe Grits in Dorset and perhaps the Lower Limestone (Hambleton Oolite)

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[1] Not invalidated by *Ammonites subcordatus* d'Orbigny, 1845, *Géol. Russie*, p. 434, pl. xxiv, figs. 6, 7, a Kimeridgian *Amoeboceras*.

[2] The type specimen is in the Calcareous Grit matrix of this district, not Oxford Clay as asserted by Healey and Buckman. The original label probably read " Hinton near Semington ".

	Zoues	Subzones	Dorset	Purton	Woodham	Warboys	Yorkshire
LOWER OXFORDIAN	CORDATUM	cordatum (= subcordatum = cardia)	? Nothe Grits	[Calcareous Grit of Seend] Clay not exposed			Calcareous Grit of Birdsall
		costicardia	Red Nodule Beds	Red Nodule Beds			Passage Beds of the coast
		bukowskii	Jordan Cliff Clay and Furzedown Clay	Beds 4, 5		Non-sequence	Scarborough Ball Beds
	MARIAE	praecordatum		Beds 1–3		Bed 8 Beds 1–7	? Lower Calcareous Grit and Oxford Clay
		praecordatum and scarburgense					
		scarburgense			Beds A, B		
	LAMBERTI		Tidmoor Point Clay		Bed C		Hackness Rock

Revised correlation table of the Lower Oxfordian at English localities.

in Yorkshire. If this inference is correct, the Lower Calcareous Grit of Birdsall is later than the Passage Beds of Scarborough; namely, on approximately the horizon of the Lower Limestone north of the Vale of Pickering and Coxwold Gap. At Purton there is plenty of room for the subzone in the 100 feet of unexposed clay and 60 feet of Calcareous Grit above the highest bed seen in the pit.

Provisionally, therefore, the Cordatus Zone is divided into three subzones, of which the two lowest are fixed by observation at Purton and in Yorkshire, and the highest is still inferential. Appropriate indices are *C. bukowskii* Maire, *C. costicardia* Buckman, and *C. cordatum* (J. Sowerby) (= *subcordatum* Pavlow) (see Table herewith).

The Vertebrale Zone, referred to by Spath in numerous papers (lastly in 1939, p. 89) has no existence in fact, since *C. vertebrale* is a fossil of the Plicatilis Zone in its type district (Oxfordshire and Berkshire). It has forerunners in earlier zones, for example, *C.* (*V.*) *quadrarium* Buckman in the Red Nodule Beds and *C.* (*V.*) sp. nov. in the Ball Beds of Scarborough and bed 4 at Purton.

Nor is there any separate Excavatum Zone (Spath, 1939), for *C. excavatum*, like *C. vertebrale*, is a characteristic companion of *Perisphinctes plicatilis* in the type locality.

The Cordatus Zone is in fact immediately followed by the Plicatilis Zone (Arkell, 1936, p. 153), of which the earliest ammonite-bearing beds are either the epibole with *Aspidoceras catena* at Marcham, Berkshire, or those with small Cardiocerates at Arngrove, Bucks (Arngrove Stone) and Heersum near Hanover (Lower Heersum Beds). Further discussion of the Plicatilis Zone, however, lies outside the scope of this paper.

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The Recent History and Pleistocene Deposits of the Plateau North of Lake Eyasi, Tanganyika

By P. E. Kent

ONE of the objectives of the East African Archaeological Expedition of 1934–5 was the examination of the plateau north of Lake Eyasi—the Vogel River area—where, it was hoped, a continuation of the richly fossiliferous Oldoway[1] Middle Pleistocene lake beds would be found. This hope was essentially realized; deposits with an interesting Middle Pleistocene fauna a little earlier than that of Oldoway were found, with the difference that they were entirely terrestrial. The development of precisely datable beds resting upon a main Rift Valley Scarp made possible a study of physiographical changes associated with the faulting.

The party consisted of Dr. L. S. B. Leakey, whose organization of expeditions to Oldoway had already made outstandingly important contributions to Pleistocene palaeontology and archaeology, G. T. Bell, Stanhope White, and the writer. The collecting was carried out by Messrs. Leakey, Bell, and White, assisted by the natives trained on previous expeditions, while the present writer undertook a geological survey, the results of which are described below. The fossils and igneous rocks found were forwarded to the British Museum, where the mammals have been studied by Dr. A. T. Hopwood, from whose work the accompanying faunal list is derived, and to whom we are greatly indebted for determination of the age of the beds and for useful discussions. Mr. W. Campbell Smith has assisted by an examination of the rock specimens, and to him also warm thanks are due. Dr. Leakey determined the human artifacts obtained.

PHYSIOGRAPHY

The Rift Valley and the Giant Craters.—The general characters of the Eyasi Rift are excellently shown by the G.S:G.S. maps, largely founded on the survey of Jaeger (1913), and D. R. Grantham has more recently described the fault scarp. The Rift Valley trends N.E.–S.W., and is flanked by two very unequal scarps—the north-westerly attaining a height of

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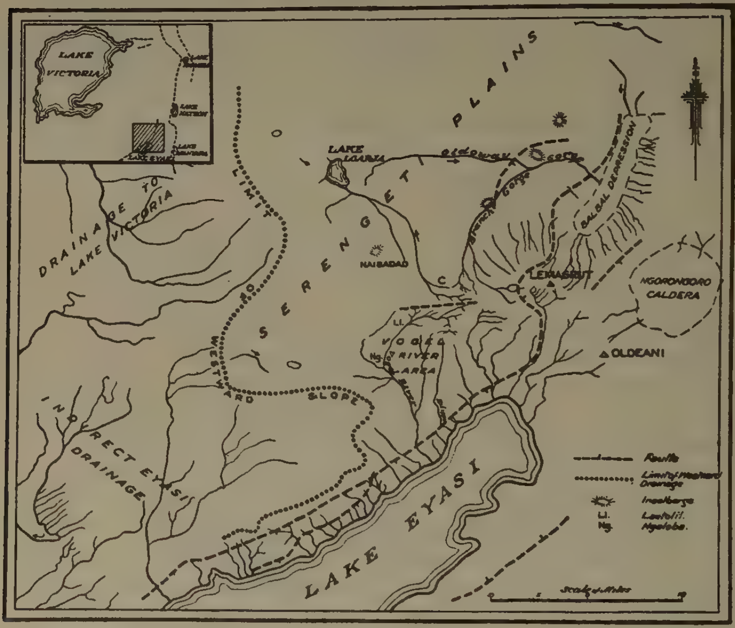
[1] Dr. Hopwood has pointed out that a more correct spelling is "Olduvai". As, however, the name Oldoway is used by many authors, including the Tanganyika Geological Survey, and has been incorporated in the culture type name "Oldowan", it seems best to continue its use.

900 metres above the lake, the south-easterly only 200–300 metres. The north-westerly scarp reaches its maximum elevation near Speer Mountain, but maintains a height of some 500 metres to the foot of Lemagrut, one of the two volcanoes which block the end of the Rift Valley. At least a part of the faulting post-dates the formation of Lemagrut, and a clearly marked scarp can be traced crossing the western side of the mountain (giving the appearance of a somma) and running into the Balbal fault, which cuts the Middle Pleistocene Oldoway Beds (Text-fig. 1).



TEXT-FIG. 1.—Drainage of the Country North of Lake Eyasi.

It is thus evident that the Eyasi fault is partly represented by the Balbal fault.

Bailey Willis (1936, p. 252) has recently suggested that the Eyasi Rift Valley continues north-eastwards to join the " Gregory Rift Valley ", and that the Ngorongoro depression (considered by earlier authors to be a large caldera) is a section which has been isolated by the development of volcanoes. For this hypothesis there is a good deal to be said—particularly as small fault scarps in the correct position can be traced cutting the volcanic mountains beyond Ngorongoro—but in the opinion of the present writer the position is rather less simple.

Firstly the writer can confirm from personal observation that the walls of Ngorongoro are as steep on the south-west as on the north-west and south-east sides, so that at least one of the walls which should show the relatively gentle slopes of a volcanic hill has actually the sharpness of a fault scarp. Secondly, the floor of the depression stands 700 metres higher than Lake Eyasi, and is even higher than the undisturbed peneplain, so that it does not show the depression characteristic of Rift Valley floors. Also, the outer slopes of the mountain show gradients identical with those of the neighbouring volcanoes, so that it is difficult to avoid the conclusion that Ngorongoro also originated as a volcanic mountain (the gneiss which Willis found being perhaps an inselberg engulfed in the eruption). The various facts may be reconciled by suggesting that Ngorongoro developed a caldera unique in the group of mountains because of its position above long-established lines of weakness, which assisted the subsidence and defined its area.

Lemagrut illustrates again the connection between volcano and rift, for the branch fault which links the Eyasi and Balbal scarps is deflected to a semi-circular course with increase of throw in the upper part of the mountain. In this case it might be suggested that incipient caldera formation has modified in detail the course of the fault.

Some of the faults which cut the Middle Pleistocene of Oldoway are curved (the course of the most westerly was plotted, and is shown on the accompanying map), and it has been suggested that they are due to subsidence associated with vulcanicity. As they pass into the true rift faults (which continue far beyond the volcanic region) the curving is presumably to be regarded as local deviation due to previous development of incipient subsidence faults.

The Drainage of the Country North of Lake Eyasi.—The drainage features of the Vogel River area and the Serengeti plain beyond are of particular interest, and throw light on the recent history of this region between Lake Victoria and the Rift (Text-fig. 1). In the west the drainage is westwards, partly to Victoria and partly (by a circuitous route) to the southern end of the Eyasi trough. East of this, in an undissected part of the peneplain, on the water divide between Victoria and the Rift, lie a series of local drainage basins, of which Lgarja is the largest. Then comes the eastward drainage: Oldoway Gorge in the north, cut back in a series of youthful fault scarps in soft sediments, and shorter rivers draining to Eyasi further south. Most of the latter are only 2 or 3 miles in length, as the upfaulted block was tilted away from the Rift and its surface is drained in the opposite direction, but the Vogel and adjacent rivers are longer as they were initiated on a surface of freshly deposited Pleistocene beds, which had an original slope greater than the amount of tilting.

As there is good reason to believe that the undisturbed peneplain sloped westwards from a continental divide on the east side of Serengeti (Willis, p. 143), the absence of dissection of the present Victoria-Rift water parting is an indication that one of the first modifications of the plain was reversal of slope of the area to the east of it (which now varies from approximate horizontality to gentle eastward slopes near Oldoway). The subsequent history of the area on the west has been one of increasing dissection accelerated by the downwarp of the Victoria basin. The slight lowering of Serengeti, however, is a movement in the opposite direction to the continental warping and to the tilting associated with the Rifts, and its curving westerly margin (shown by the water parting on the map) tends to be concentric with the volcanic centres, and hence is probably connected with their development. The small independent basins near the watershed are probably due to original irregularity of the Serengeti subsidence. The formation of the Oldoway lake basin (which may well have come into existence in the early Pleistocene as a result of a second volcanic subsidence), and the erosion which has rapidly followed the faulting of its soft sediments, are now leading to capture of the Lgarja drainage area, which will at no distant date be tributary to the Balbal depression.

Three groups of rivers drain the west side of Lemagrut. In the north the Oldoway side gorge collects the water of numerous small ravines on the north-west side of the mountain, on the west shallow valleys drain towards Lgarja Lake, and in the south-west and south the drainage is towards Lake Eyasi. One of the points at once indicated by the map and still more striking on the ground is that Lgarja drainage has been to a large extent beheaded by the more active systems to the north and south. The Lgarja River (as it may be named) occupies a very broad valley, of mature appearance even in its (present) upper parts, a striking contrast to the ravines and gorges on the north and south. At the point C on the map there is one of the best examples of active capture which one could wish to see : one of the broad valleys of the Lgarja hangs, truncated, high up on the wall of a steep-sided ravine-like valley of the Oldoway side gorge system. The capture, which is evidently still in progress, is presumably due to the advantage gained by the northern and southern rivers as a result of the late Middle Pleistocene faulting, which has favoured deep incision, while the Lgarja stream remained unaffected by this.

The valleys draining towards the Eyasi Rift are narrow and deeply incised near the rift scarp, but are broad and open in their middle parts, where residual hills show that 100 feet or more of soft ashy beds have been denuded from a considerable area. Ravines form the upper reaches of the valleys, and commonly occur incised in the broad valleys of the middle reaches—an arrangement recalling Oldoway. Among these gorges are remarkable examples of the vertical weathering forms which are produced in arid climates in soft material—the Middle Pleistocene beds are carved into pillars, walls, and cliffs giving an appearance remarkably similar to the exhumed foundations of a Roman city. At least part of these arid erosion forms has been uncovered by modern denudation from beneath Ngaloba Beds, and probably dates from the early Upper Pleistocene dry period (see below).

One feature of the Vogel system is of particular interest—one of its branches has cut a ravine through the low ridge dividing two valleys (west of Ngarusi hill) and has captured part, if not most, of the head waters of the Eilippi. A line of trees (the usual local accompaniment of a water course) still runs from the captured streams to the Eilippi, but the drainage is now towards the north. Since the Eilippi has a much shorter course towards Eyasi, this capture must be the result of tilting away from the Rift Scarp, which has locally assisted northward drainage and perhaps also reduced the gradient of the Eilippi relatively more than that of the deeply incised Vogel.

This tilting presumably occurred at the end of the Middle Pleistocene, when the Oldoway-Balbal faults were formed (the Vogel river beds having by then already been subject to denudation for a considerable period), a conclusion supported by the presence in the valleys north and west of Ngaloba of relatively thick deposits of basal Upper Pleistocene beds, the survival of which seems to be due to formation of small basins by the same tilting.

STRATIGRAPHY—THE VOGEL RIVER SERIES

The Oldoway Series consists of lacustrine Middle Pleistocene (Beds I–IV) resting upon an irregular lava surface, into which in early Upper Pleistocene times a valley was cut and gravels and aeolian deposits (Bed V) laid down. The Vogel River

Series demonstrates the history of the area beyond the limits of the Oldoway lake, and extends the account back to an earlier period.

Upon the upfaulted gneissic peneplain, deposition commenced with accumulation of pale fine tuffs—the Laetolil Beds—which are for the most part unbedded, and yield a terrestrial fauna rather earlier than Oldoway I, with stone implements more primitive than the pebble tools of that horizon

Upon a somewhat irregular surface of the Laetolil Beds agglomerate was deposited locally and a flow of olivine-nephelinite lava covered a wider area. There is an indication that deposition of beds of the Laetolil facies was temporarily resumed after this.

For a long period subsequently erosion became the dominant factor, and the area developed its present mature topography, low residual hills showing the former thickness of the earlier deposits. Then, apparently early in the Upper Pleistocene, the upper member of the Vogel River Series was deposited, consisting of pale yellow fine ashy clays with zones of black cotton soil, named the Ngaloba beds from the type locality. This material was widely deposited over the irregular surface of the Laetolil Beds, and reached a thickness of some 20 feet in two valleys in the west.

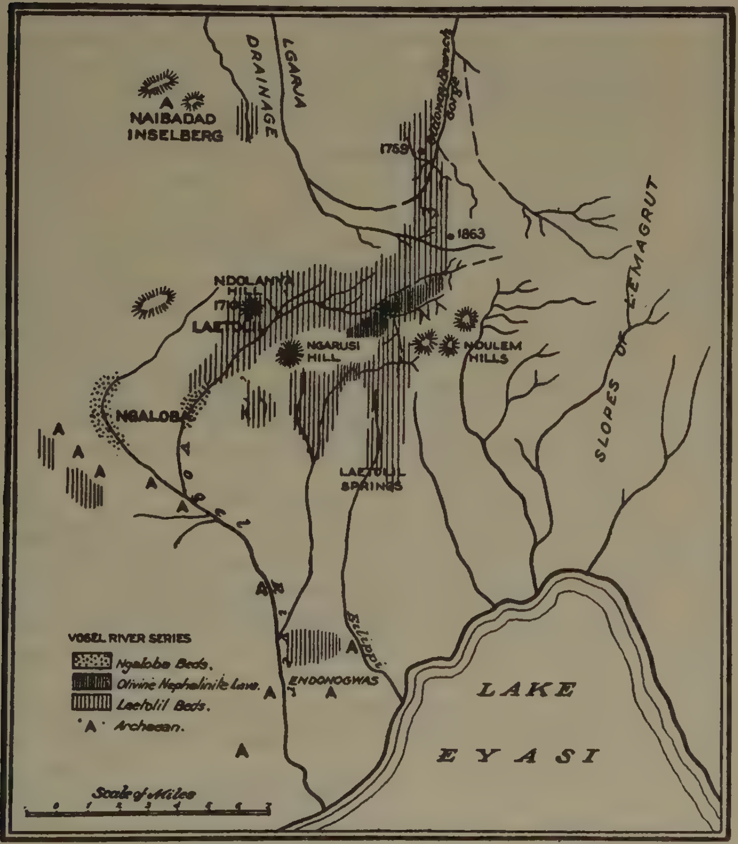
Laetolil Beds.—The Laetolil Beds consist of subaerially deposited tuffs, apparently derived from the Giant Craters to the east. They yielded a fauna which was entirely terrestrial, there being no fish or hippopotamus remains as at Oldoway. Instead, fragments of ostrich eggshell were common and widespread, and other indications that the fauna lived on the spot were provided by the discovery of a partridge-like avian egg, and by a nest of eleven reptilian (probably tortoise) eggs by White.

Dr. Hopwood's identifications of the mammals are as follows :—

Cercocebus ado Hopwood, a new species.
Elephas antiquus recki Dietrich.
Elephas aff. planifrons Falc. and Caut.
Deinotherium bozasi Aram.
Sivatherium sp.
Giraffa sp.
Hipparion sp.
Equus sp.
Rhinoceros simus Burch.
Cf. *Metridiochoerus* sp.
Antelopes and Chelonians, indet.
From the basal beds : *Mastodon* sp.

In this assemblage *E. antiquus recki* provides a link with Oldoway, where it is the characteristic proboscidian. *E. aff. planifrons*, however, is an earlier type unknown at the other locality, and with a new species of *Hipparion* indicates that the Laetolil Beds are (at least in part) somewhat older than Oldoway Bed I. Pebble tools found in close association with the bed by

Dr. Leakey confirm the earlier date. The *Mastodon* from the basal beds is identified as a species which occurs in the Lower Pleistocene of Kanam, Kenya. This may range up into the subsequent period (*Mastodon* fragments are known from Oldoway) but it is quite likely that the earliest Laetolil Beds are, in fact, Lower Pleistocene.



Text-fig. 2.—Geological Sketch-map illustrating the distribution of the Vogel River Series.

The presence of terrestrial Middle Pleistocene at this locality proves that the Rift was already in existence, for Stockley (1929) and Oates (1933) have shown that within an expanded Eyasi basin lacustrine Middle Pleistocene beds were being deposited.

The base of the Laetolil Beds, seen in the south-west on the lower slopes of Speer Mountain and near the Rift Scarp, consisted of yellow and orange moderately fine tuff passing upwards into pale-grey, fine pure crystal tuff, with abundant small fragments and scattered angular blocks of gneiss which became less common upwards. This was the source of the above-mentioned teeth of *Mastodon*. The gneiss surface beneath the beds was in some places hummocky and irregular, but elsewhere showed rounded tabular forms. At higher levels the main mass of the beds consisted of pale-grey, calcareous, fine tuff (fine to coarse sand grade), poorly bedded, with local thin partings of grey ashy clay and occasional strings of pebbles. Uneven distribution of lime, leading to local hardening of the beds, in some cases caused a development on weathering of rounded pillars and irregular "mushroom" forms. A characteristic concretionary structure was a raised ring of cemented ash surrounding a "gravel" of twig-like concretions. The beds were visible for nearly 50 feet at Laetolil, where the lower part of the exposure yielded the main part of the fauna listed above. Overlying them was approximately 40 feet of yellowish-grey softer ash, occasionally thinly bedded—possibly from deposition in local pools.

At Laetolil Springs this bed was succeeded by 5 or 10 feet of agglomerate, containing a lava identified by Mr. Campbell Smith as a nephelinitoid phonolite. At other localities examined this stratum was absent, and the irregular surface of the ashy beds succeeded by a flow of dark green olivine-nephelinite lava. This is described by Mr. Campbell Smith as quite distinct from the olivine-basalt of the basal lava flow of Oldoway, and it may be contemporaneous with the earlier part of the Oldoway lacustrine series, which according to Finckh includes a nephelinite tuff near the mouth of the Gorge.

On Ndolanya Hill (1,710 s.h.), the lava appears to dip under a small thickness of tuffs of Laetolil type, so that it is possible that sedimentation was resumed for a short time.

Ngaloba Beds.—After eruption of the olivine-nephelinite over the Vogel River area, valley erosion began and reached an advanced stage. Deposition was not resumed until the Upper Pleistocene (probably the abnormal rainfall of the Middle Pleistocene prevented earlier accumulation of subaerial deposits) when, with the ending of the pluvial period, began accumulation of the Ngaloba Beds.

These consist of blue-grey or yellowish ashy clays, and form a nearly continuous thin covering over the whole area from the valley floors to the hill-tops, extending as far west as Naibadad Inselberg,[1] and northwards to the upper part of Oldoway Branch Gorge.

In the parallel valleys near Ngaloba the formation reaches a greater thickness. The section at Ngaloba was as follows :—

	ft.
Black cotton soil	3
Yellow-grey fine ashy clay, showing rhythmic banding—in each unit the clay is light below, darkening upwards to a black line, followed by light clay again. At least four cycles visible. On an irregular surface	12
Chocolate brown ash, bleached white in the uppermost part. Base not seen	5

The bleached irregular surface of the ashy bed indicates an interval of slight erosion and weathering, and in the ashy clays above the rhythm appears to be due to cessation of deposition, with slight formation of cotton soil. In the valley to the west exposures were not so good, but cotton soil was seen covered by ashy clay.

It was interesting to notice that the Ngaloba Beds were almost invariably fine-grained, and that even when debris of hard beds covered the surface no pebbles occurred in the ashy clays. This indicates that transport (particularly water transport) of materials was at a minimum at the time of deposition, and since numerous worked flakes of early Levallois type were found on the surface of the beds (not certainly *in situ*, but very probably derived therefrom), there is a strong degree of probability that the formation dates from the time of the dry period which Solomon and Leakey (1931) have proved in Kenya immediately after the Middle Pleistocene faulting. Supporting evidence of the dry period is provided by ravined surfaces of the Laetolil Beds beneath the Ngaloba clays.

At Oldoway, on the other hand, river erosion and formation of gravels are typical of Lower Bed V, and this belongs to the Gamblian pluvial period immediately following. The difference in age of the Upper Pleistocene deposits of the adjacent areas thus reflects the fact that the late Middle Pleistocene faulting coincided with the end of the major pluvial, so that erosion at Oldoway began at the time when subaerial accumulation became again possible further south.

As the Ngaloba Beds are of terrestrial origin, their thick development at the type locality and in the neighbouring valley does not directly reflect the existence of basins. Deposition was followed, however, by the wet periods of the Upper Pleistocene, and it seems logical to suggest that the rivers failed to remove the deposits at these points, and failed to cut through them to solid rock, as at other localities, because renewal of the faulting had led to a repetition of the westward tilting of the plateau block, with formation of two small basins by local reversal of slope of the valley floors.

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[1] This is named " Olduwai " on the G.S:G.S. 1:300,000 map, but the name " Naibadad ", given to us by Masai inhabitants, is used here to avoid confusion with the various inselbergs close to Oldoway Gorge.

The widely occurring surface limestone was seen resting directly on the Laetolil surface, and was in several cases covered by Ngaloba Beds. It therefore seems to be earlier than the surface limestone of Oldoway, which rests upon Bed V. The typical development was a grey limestone with light-red pebble-like bodies, presumably of concretionary origin.

The Connection with Oldoway

The Vogel River area was reached by travelling to the head of Oldoway Gorge, round Lake Lgarja (now a salty mud flat throughout most of the year) and thence south-eastwards past Naibadad Inselberg. In this traverse beds of the Oldoway lacustrine series were seen at intervals to within approximately 6 miles of Lgarja, exposures, however, deteriorating and becoming rarer. Around Lgarja itself grey crystal tuffs exposed in small gullies were developed in the facies of the Laetolil Beds. It may be noted that the similarity of facies does not necessarily involve identity of age: this occurrence may be a terrestrial equivalent of part of the Oldoway Series. A gully 1½ miles due east of Naibadad Inselberg—an isolated exposure in a broad obscure area—showed ashy clays similar to the Ngaloba Beds resting on pale tuffs of Laetolil type.

For additional information about the relations of Oldoway and the Vogel Series, a traverse was made northwards from the Vogel area to the Oldoway Branch Gorge. The Vogel River Series was exposed frequently to the 1,863 s.h. of the G.S:G.S. map in valleys draining towards Eyasi, with lava capping the ridges. Good exposures were also seen in the upper part of the Oldoway Branch Gorge from this point to the 1,759 s.h., and again at a point 2½ miles north of the latter, 1 mile west of the Gorge. In the southernmost ravines of the Branch Gorge a total of 45 feet of tuffs was exposed—pale above, dark brown at the base, with abundant (but unidentifiable) bone fragments. The northernmost of these exposures are in ground falling rapidly towards the Oldoway plain. For the next 2 or 3 miles the ground was obscure, and then exposures of the upper part of the Oldoway lake beds began and continued northwards.

As there was no evidence of a fault scarp, it seems that the margin of the Oldoway Lake was formed by this rising ground. The distribution of residual hills of the Laetolil Beds south of Oldoway, with the evidence of initial radial drainage, indicates, in fact, that they were deposited to maximum thickness near the 1,863 s.h., thinning from there towards north, south, and west, as a broad low spur of Lemagrut. This points to Lemagrut as the source of the Laetolil tuffs, the precise arrangement being probably the result of prevalent easterly or east-north-easterly winds.

SUMMARY

The area north of Lake Eyasi is thus one where the effects of rift movements, continental warping and vulcanism have interacted. One of the first events affecting the ancient peneplain was the slight eastward tilting of the southern Serengeti area,

	Human Cultures	Oldoway	Vogel River
Recent	Neolithic	DUST	ALLUVIUM
Upper Pleistocene	Aurignacian Levallois	Gorge Erosion SURFACE LIME BED V*b* (aeolian) BED V*a* (fluviatile) Valley Erosion	Gorge Erosion V*b* locally NGALOBA BEDS
Middle Pleistocene		Faulting	Tilting
	Acheulean	BED IV (lacustrine) BED III ,,	SURFACE LIME. Valley Erosion to mature topography
	Chellean	BED II ,, BED I ,,	TUFF locally
	Oldowan	BASALT	OLIVINE NEPHELINITE LAVA
		(Unknown)	AGGLOMERATE locally. Erosion elsewhere LAETOLIL BEDS. Valley Erosion of Archaean Surface
Lower Pleistocene			
		Main period of formation of Giant Craters, blocking Rift Valley	
Pliocene ?			Main Faulting

and probably about the same time came the first post-peneplain formation of the Eyasi scarp and the beginnings of the Giant Craters. Denudation of the fault scarp has been taking place for a relatively long period, and Pliocene and Pleistocene sediments must have accumulated to considerable thickness in the fault trough, although the earliest known are Middle Pleistocene beds deposited in the expanded Lake Eyasi of the main pluvial period.

On the plateau surface in the Vogel River area pale volcanic ash drifted like snow from the volcanic centres to the east, and entombed some of the highly interesting archaic mammals of the African Middle Pleistocene. A flow of lava closed the period of accumulation locally, and extensive denudation of the earlier Vogel River (Laetolil) beds began. A little to the north sedimentation continued throughout most of this interval in the Oldoway lake, and this ceased with the ending of the pluvial period and the formation by faulting of the Balbal depression. This later period of faulting, although the curving scarps suggest the influence of volcanic subsidence, was presumably part of the true rift movements, for major rifting at this period (the end of the Middle Pleistocene) has been clearly recognized in Uganda and Kenya. Renewal of the Eyasi faulting is in fact indicated by the effects of tilting on drainage and local sedimentation in the Vogel area.

The table on p.183 illustrates the sequences of events as compared with the standard succession at Oldoway.

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The Ordovician Rocks of the Builth District

A Preliminary Account

By Professor O. T. Jones and Professor W. J. Pugh

THE Builth district was visited by one of us (O. T. J.) in the spring of 1939 with a view to arranging an excursion for the International Geological Congress which was to have been held in London in 1940. Amongst other places the magnificent range of quarries in the Ordovician volcanic rocks of Llanelwedd, near Builth, was examined. Beyond the western end of the quarries a striking boulder bed was observed which promised to give an insight into a remarkable episode in the history of the district. This bed is shown on the 1 in. Geological Survey Map, Old Series, Sheet 56, S.W.

Since the days of Murchison and the Geological Survey the Ordovician rocks of the Builth-Llandrindod district have been mapped and described by Mr. Henry Woods, Miss C. Chamberlain, Mr. R. O. Roberts, and Dr. G. L. Elles (see G. L. Elles, *Quart. Journ. Geol. Soc.*, xcv, 1940, 383–445). Roberts, while a post-graduate student in the University of Cambridge, mapped the whole of the Ordovician area on the scale of 6 inches to the mile and his field maps and notes were afterwards placed at the disposal of one of us (W. J. P.). During our preliminary examination we found them of considerable service in directing us to localities and sections of interest. We soon realized, however, that maps on this scale were quite inadequate to portray satisfactorily the geological structure and we decided therefore to map the district anew on the scale of 25 inches to the mile. This investigation, which has occupied us for about six months in the field, has so far extended for some 5 miles north-east of Builth. We have been led to conclusions regarding the geological structure and history of the area which differ fundamentally from those expressed by previous investigators and we feel that a preliminary statement may be of interest at this stage, although a further extension of our survey may lead to minor modifications in the conclusions expressed here. Moreover, in view of the present circumstances, a detailed account may be delayed for a considerable time.

Experience of the remarkable lateral changes in the characters of the rocks has made it clear that the most satisfactory method of investigating the district is by mapping from the south towards the north, which is the direction in which the major changes may be most readily appreciated.

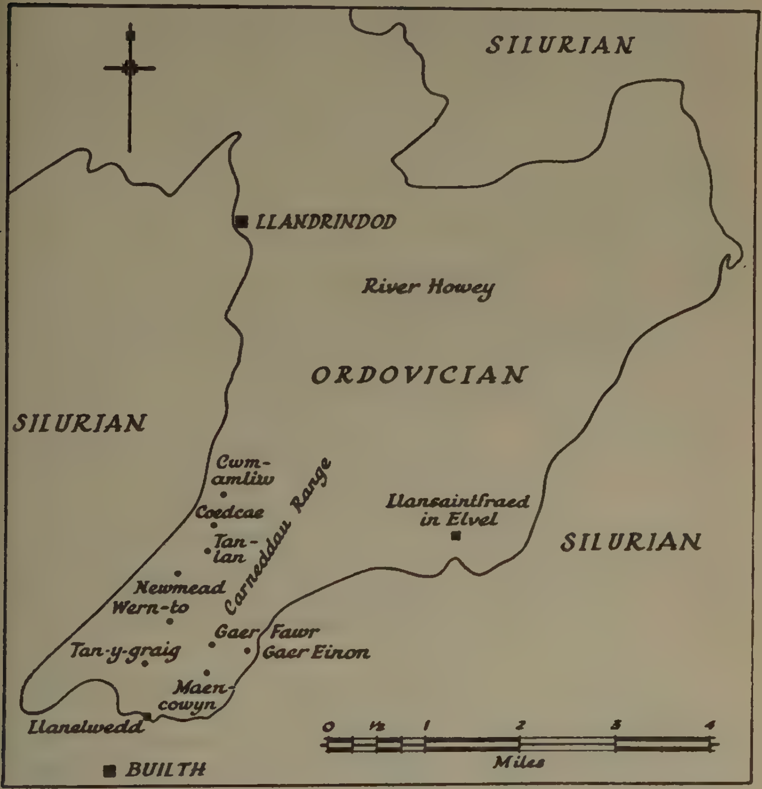
The general succession may be summarized as follows :—

Black Shales with *Glyptograptus teretiusculus*, etc.	
	Unconformity
Cwm-amliw Series . .	Rhyolitic Ashes and Ashy Shales
Newmead Series . .	Rhyolitic Ashes. (Tan-lan) Pyritous Felspar Sands and Boulder Beds. (Newmead) Grey Felspar Sands and Boulder Beds. (Tan-y-graig)
	Unconformity
Builth Volcanic Series .	Keratophyres, Breccias, and Ashes Upper Spilites Felsite Conglomerate or Agglomerate Lower Spilites Bouldery Spilitic Ashes Pebbly Felspar Ashes Fine Grey Ashes and Shales Red Agglomerate and Ashes
	Unconformity
Llandrindod Series . .	Rhyolitic Ashes Shales with thin Ashes
	Base not seen

The oldest rocks so far examined are dark, rusty-weathering, rubbly, and flaggy shales with some bands of volcanic ash. These rocks are, on the whole, poorly exposed, and although it is possible that a thickness of nearly 1,000 feet may be represented, it is doubtful if a thickness of more than 200 feet is exposed in any one section. These rocks belong generally to the zone of *Didymograptus bifidus*, but an undefined portion of them, probably in the upper part of the zone, has recently been referred by Dr. G. L. Elles (op. cit) to the subzone of *Didymograptus speciosus*. Parts of this group are richly fossiliferous.

These rocks are succeeded by coarse and fine rhyolitic or keratophyric ashes with usually a well-marked, coarse, rubbly group at the base ; the upper part usually consists of fine-grained well-bedded ashes, cream-coloured and with flinty fracture. The Llandrindod Ashes have a maximum thickness of 200 or 300 feet and are, in general, well exposed. The lithological characters of the shales immediately underlying them are so different from place to place as to lead to the suspicion that the ashes are resting on different horizons in the shales and this suspicion is strengthened by the local abundance of shale debris in the basal beds of the ashes. It is not possible at present to say whether the ashes should be attributed to the subzone of *Didymograptus speciosus* or to a higher zone.

The rocks of the Builth Volcanic Series are almost continuously exposed throughout the area and the mutual relations of the groups can be examined in numerous sections. It has thus been possible to trace the lateral variations in this series and to establish the correlation of the groups in different parts of the district. Near Builth it attains a thickness of about 2,000 feet.



TEXT-FIG. 1.—Map showing area occupied by the Ordovician rocks of the Builth-Llandrindod district, taken from Old Series Geological Survey Map, Sheet 56.

The series begins with conspicuous agglomerates and associated ashes well seen near Maen-cowyn. These are dark green, calcareous rocks with fragments of fine pumice. On weathering the exposed surfaces generally assume a reddish-brown colour which has suggested the name given in the table of succession. These red-weathering agglomerates and ashes usually rest on the volcanic rocks of the Llandrindod Series, but in the country about Llansaintfraed in Elvel they are in contact with various horizons in the underlying shale group. Wherever the junction has been examined the Red Agglomerate group rests on an uneven surface of the underlying rocks, usually with a characteristic basement bed and there is no doubt that there is an unconformity at this contact. The agglomerates and ashes are in places very fossiliferous, one of the most remarkable features being the great abundance of thin rod-like structures which have been attributed to anchoring spines of sponges. This group when traced northwards diminishes greatly in thickness and becomes finer in grain.

It is overlain by fine-grained, grey ashes with bands of dark, fossiliferous shales. When traced northwards this group becomes almost wholly shales as in the development in the upper part of the River Howey, where it is represented by the well-known *Didymograptus murchisoni* shales. In that river section the *Didymograptus murchisoni* shales pass downwards by alternations of shales and ashes into the lateral equivalent of the Red Agglomerate group which, although much finer in grain, nevertheless displays its unmistakable lithological features and rests on the Llandrindod Ashes with a characteristic basement bed and erosion surface. The total thickness of the shale group and the underlying Red Agglomerate group in the Howey does not exceed 300 feet as compared with 900 feet or more in the southern part of the district.

The Pebbly Felspar Ashes are coarse-grained and contain well-rounded pebbles of felsites and other rocks. They are best developed about the middle of the district on the Carneddau Range, where they probably attain a thickness of about 300 feet. These rocks are in places agglomeratic and include many shale fragments.

The Bouldery Spilitic Ashes are remarkable rocks which make their appearance at the base of the Lower Spilites at the southern end of the Carneddau Range. They rapidly increase in thickness northwards to at least 250 feet. The included boulders are rounded and are of various types of vesicular spilites with occasional other igneous rocks and usually range in size from 3 to 12 inches. The boulders are more numerous and larger in the central area of its development and in places reach a diameter of several feet. The matrix commonly consists of densely packed large and small felspar crystals similar to the porphyritic elements of the spilites. In the more bouldery developments the matrix is sparse and difficult to distinguish from the included boulders.

Both Lower and Upper Spilites have hitherto been regarded and mapped as intrusive rocks (diabase). Their extrusive character is demonstrated beyond question in the great quarry sections near Llanelwedd, where they appear to be made up of numerous thin flows separated one from another by sharply defined surfaces. These surfaces are reminiscent of layers of large " pillows " and occasionally shale pockets occur in the hollows of the surface or between the " pillows ". They consist of coarsely porphyritic rocks with conspicuous large vesicles, filled with calcite or chlorite or both ; on weathering they present a characteristic honeycombed appearance. Between the Lower and Upper Spilites there is a bed with rounded pebbles of felsite up to a foot in diameter set in a matrix of angular ashy fragments. This bed can be traced continuously for about ¾ mile northwards from the Llanelwedd Quarries and maintains a thickness of about 30 feet. Apart from other evidence this would have been sufficient to throw doubt on the supposed intrusive nature of the adjoining spilites. The combined thickness of the spilites in the quarries is about 700 feet.

The highest group of the Builth Volcanic Series which is seen consists of keratophyres, keratophyric breccias and ashes, and a fine-grained splintery keratophyre weathering with a white skin, the latter being overlain directly by the basal beds of the Newmead Series. The thickness is estimated to be about 250 feet.

The Newmead Series rests with marked unconformity on the Builth Volcanic Series and when traced northwards, one after another of the members of the latter series is overstepped until near Coedcae, the local base of the Newmead Series rests on the upper part of the Bouldery Spilitic Ashes. The Newmead Series begins with grey felspar sands and these are succeeded by pyritous felspar sands. These sands include at various levels remarkable concentrations of well-worn boulders up to several feet in diameter derived from the Builth Volcanic Series. The uppermost beds consist of fine, rhyolitic ashes which like the underlying sands are in places abundantly fossiliferous. There is a systematic overlap from south to north within the series so that at Coedcae only the uppermost beds are present. The average thickness of the series is about 300 feet but is locally greater.

The phenomena that accompany the unconformity at the base of the Newmead Series are amongst the most striking in British geology. The distribution and characters of the boulder beds, their relation to the associated sands and the rocks beneath them recall forcibly the features of a modern rocky shore and boulder-strewn sands. Further, in many places, the Builth Volcanics project through the Newmead Series. These projecting bosses are stacks of the underlying rocks which rose very sharply from the shore level and were overwhelmed by the Newmead Sands during the submergence of the area. The distance at which these occur from the base of the Newmead Series combined with the present dip of the sediments gives an indication of the height to which the stacks rose above the general level of the shore. One of them near Wern-tô appears through almost the whole thickness of the Newmead Series and may have reached a height of about 400 feet. Furthermore, the near-by cliffs made of Builth Volcanic rocks appears to have risen sharply to a height of at least 100 feet above the level of the shore. In many places examination of the stripped surface of the Builth Series reveals how the sands penetrated into cavities and fissures in what was at that time a wave-worn, rocky foreshore.

Near Cwm-amliw, a new group of white, unfossiliferous, flinty rhyolitic ashes makes its appearance below the *Glyptograptus teretiusculus* shales. It rests on about the same horizon in the Bouldery Spilitic Ashes as the Rhyolitic Ashes at Coedcae and seems to occupy a place in the north of the area similar to that of the Newmead Series farther south. There is little doubt that the great unconformity at the base of the Newmead Series is represented at Cwm-amliw at the base of this rhyolitic series, all the members of the Newmead Series having in turn been overlapped. These rhyolitic rocks, which are nearly 200 feet thick at Cwm-amliw but thinner farther north, are overlain in one place by *Didymograptus*-bearing shales. We have been able to show, therefore, that all the Builth Volcanic Series and the overlying Newmead Series together with the great unconformity that separates the two series correspond to the time-interval of the *Didymograptus murchisoni* Zone in whole or in part.

The shales with *Glyptograptus teretiusculus* are soft dark shales which rest unconformably upon various members of the Newmead and Cwm-amliw Series. The basal beds of the shales can be seen in contact with the pyritous felspar sands of the Newmead Series, the Cwm-amliw Rhyolitic Series and in one place they rest upon the Bouldery Spilitic Ashes of the Builth Volcanic Series. We have not yet seen the shales in contact with the lower grey felspar sands of the Newmead Series, but the two groups are adjacent to one another for nearly a mile.

At various places in the northern part of the area there are numerous oval and sub-circular masses of keratophyre which form conspicuous topographical features. They often exhibit an intimate platy structure and their distribution and relation to the surrounding rocks are of considerable interest. Dolerites occur as large sills intrusive into shales and as dykes of varying length and width.

The two prominent conical hills of Gaer Fawr and Gaer Einon, in the southern part of district, are composed of rock-types similar to those which occur in the main outcrop of the Builth Volcanic Series some distance away to the west. The mode of occurrence of the rocks in these hills presents puzzling features which are under investigation.

In addition to the varied vulcanicity, erosion, and deposition within the limits of the *Didymograptus murchisoni* Zone, the subsequent tectonic history is no less remarkable. The area examined is crossed by three great belts of faulting ranging nearly east and west. These are tear faults, the country having been shifted bodily along these great fracture belts by anything from a quarter to half a mile, the aggregate movement being nearly a mile in a little over 3 miles along the strike. In each case the relative movement is to the east on the north side. There is little or no evidence of vertical displacement. The component faults of each belt form an anastomosing series. There are also numerous strike-faults and many others forming systems of various types, so that there are few, if any, Ordovician areas which reveal so complex and intimate a fault pattern. In view of the general excellence of the Old Series Geological Survey Maps, it is remarkable that no faulting is shown on these maps of the Builth-Llandrindod country. The earth movements occurred some time after the deposition of the *Glyptograptus teretiusculus* shales and before the close of the Upper Llandovery. Movements in this time-interval are not well represented or have not been generally recognized elsewhere in Wales.

"Algal Dust" and the Finer-grained Varieties of Carboniferous Limestone

By Alan Wood

(PLATE II)

Characters of Algal Dust

CERTAIN of the Lower Carboniferous algae are preserved as moulds in a fine-grained calcareous matrix precipitated by their own life processes. The cell walls of the alga are not preserved. This observation applies to the genera *Ortonella*, *Mitcheldeania*, *Bevocastria*, and *Girvanella*.[1] In the case of *Mitcheldeania* the filaments are so close together and so parallel that an impression of a definite wall may be obtained, but occasional irregularities and a comparison of the microstructure with that of other forms leaves no doubt that this too is a precipitate.

The material surrounding the algal tubes is similar in texture in all four genera. It consists of an extremely fine-grained aggregate of calcite crystals. On weathering this aggregate becomes minutely " frosted " resulting in the well known porcellanous appearance of algal nodules. In section, however, it appears dusty and dark (see Pl. II, Fig. 1). This lack of transparency is here held not to be due to any argillaceous admixture, or to any trace of organic matter, but to loss of light by total internal reflection at junctions in the thickness of the slide. The effect would be heightened by the high birefringence of calcite. Direct observation confirms this theory. Many dark spots can be seen in the slide (at a magnification of 600 or 800 diameters) which are clearly due to refraction as they disappear gradually and become replaced by layers of crystals on lowering the microscope tube slightly. At the same time other dark patches appear, only to vanish in turn.

When the precipitate surrounding the algal threads is examined under high powers it appears to be made up of a felted aggregate of tiny stumpy needles three or four times as long as wide. The use of extremely high powers (× 800 and × 1,200), and extremely thin portions of slides (less than 10μ) shows that this " felted needle " appearance is a delusion. What are actually observed are the Becke lines round the edges of innumerable tiny crystals of calcite situated just below the point of focus of the microscope in the thickness of the slide. At this magnification, and on portions of slides where the mass-colour gives third order pinks, blues, and yellows under crossed nicols, the granules are clear; and, though observation is difficult, no argillaceous or carbonaceous matter can be seen. The grains themselves are angular with sides measuring 2–3μ and less. Since the precipitated material is so constant in its characters and so easily recognizable even under moderate magnifications, the term " algal dust " may be employed for it, when associated with algal tubes or clearly derived from algal nodules.

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[1] In this investigation metatypes of the following species have been seen. *Ortonella furcata*, *O. kershopensis*, *O. tenuissima*, *Mitcheldeania nicholsoni*, *Girvanella problematica*, and *G. staminea*. In addition specimens of *Bevocastria* sp. and *Mitcheldeania gregaria* have been examined.

The same fine-grained material, with the same well-marked characters is seen in the *Spongiostroma-Pycnostroma* group. These were considered by Garwood (1913) to be " due to precipitation of carbonate of lime in the neighbourhood of algal growths " and Pia (1937) concurred in this view. The similarity of the grain size and mode of aggregation of the calcite lends support to this theory. On the other hand the genus *Aphralysia* is now preserved as an aggregate of crystals with partly sutured junctions. The crystals have rather irregular and angular outlines and range in size from an extreme of 0·025 × 0·050 mm. down to a more usual size of 0·015 × 0·008 mm., sometimes being rather less than this. In any case the crystals are much larger than those of " algal dust ", and, as can be seen from Garwood's figures (1914, pl. xxi), *Aphralysia* is much more transparent in slide as a result. It has lately been held by Kuhn (1928) that *Aphralysia* is not an alga but a hydrozoon, and the above observations would be in conformity with this.

" Algal dust " therefore is an associate of algal action in the Carboniferous Limestone.[1] There is a complete transition from algal nodules with strongly marked tubes (*Mitcheldeania gregaria* Nich.) through forms with looser tubes (*Ortonella furcata* Garw.) to those consisting of vague aggregations of tubes (some species of *Bevocastria*). The final stage is that of the *Spongiostroma* precipitates with no definite organic structure preserved. The different appearances depend on the type of alga making up the nodule, and on the rapidity of decay of the organic matter, but the association of algal dust with algal traces appears to be constant.

How far algal dust has suffered recrystallization is a difficult problem. It is known that water under-saturated with regard to fine grains may be saturated for large ones (Eardley, 1938).

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[1] Genera with a solid calcareous framework, e.g. *Solenopora*, are not considered here. Their skeleton was formed in a different manner, and would not easily fall to powder in agitated water.

No doubt some of the finest interstital grains have vanished and this matter now forms the cement which binds granule to granule, but no other evidence of change can be seen. The material now consists of calcite[1] as would be expected and there is no evidence that inversion from aragonite has occurred. Three lines of evidence suggest that primary precipitation was in the form of calcite. Firstly, the tubes which were occupied in life by the algal filaments have sharp borders. The tubes are filled with calcite granules several times larger than the algal dust which surrounds them; and they are visible by virtue of this very difference in size and the superior transparency involved (Pl. II, fig. 1). In certain cases (particularly in *Mitcheldeania gregaria* Nich.) the tubes run gradually out of the plane of the slide. A sharp curved boundary can be seen between the calcite infilling the tube and the enveloping algal dust. If the algal dust were wholly recrystallized this boundary would tend to be indefinite. Secondly the granules of algal dust are of the same order of size as those found in the outer layers of the algal ooliths of Bradley (1929), where precipitation was certainly due to algal action. Probably then there has been no recrystallization from finer material. The third line of approach is concerned with the inclusion of algal dust in ooliths. As mentioned later (p. 197) certain ooliths associated with algal action contain fragments of algal dust. Since presumably the algal dust was suspended in the water while the ooliths were forming and was mechanically enclosed by the latter, it is reasonable to suppose that it had its present form and condition at the time. On the whole, therefore, it is considered likely that algal dust was precipitated, loosely at first, in much its present form.

LIMESTONES FORMED OF MATERIAL SIMILAR TO ALGAL DUST

(*a*) *Calcite mudstones* (Chinastone Limestones of E. E. L. Dixon, Calcaires sapropéliens of F. Kaisin in part). These rocks described by Dixon (1911) from South Wales are composed essentially of fine-grained calcite, weathering china-white but appearing dark in slide. The grain size and mode of aggregation is very reminiscent of algal dust, and occasional recrystallization phenomena are seen, resulting in the formation of larger crystals. It is undoubtedly true that these rocks grade into fine-grained bituminous limestones, but the term sapropel-limestone seems inappropriate for the purer varieties, in which the dark appearance in slide is due (to a large extent at least) to the extreme fineness of grain.

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[1] Checked by Leitmeyer and Feigel's test.

(*b*) *Grain Limestones* (Limestone Sandstones of M. Black and microbrèches of F. Kaisin. Structure grenue of L. Cayeux). These are rocks formed of rounded or subangular grains of pre-existing limestones. A suitable name is hard to devise but the rocks are consolidated limestone-sands. Fig. 3 (Pl. II) shows a typical example with grains of calcite mudstone rounded and forming a sand together with echinoderm fragments of much the same size. Here again the " sand " grains are composed of material closely resembling algal dust.

(*c*) *Pellet Limestones* (M. Black) (Structure pseudoolithique of L. Cayeux in part). In the Carboniferous Limestone it is common to find rocks formed partly or almost entirely of faecal pellets (Pl. II, Fig. 2).[1] From the observations of Eardley (1938) on the deposits of the Great Salt Lake it would appear that the faecal pellets are those of mud-eating animals and that accumulations of pellets form by current winnowing in favourable positions. The pellets are often composed of material closely similar to algal dust.

(*d*) *Clotted Limestones* (Calcaires grumeleux of French and Belgian authors).[2] A characteristic feature of clotted limestones is a partial recrystallization of the finer grained portions resulting in the formation of areas appearing light in slide (recrystallized) and darker areas (not recrystallized). There is no definite boundary between the two. Organic action has been invoked to explain the breaking down of the limestone. Algal action at least is not needed, for as Fig. 5 (Pl. II) shows, clotting can begin in sediment partly filling the interior of a gastropod shell, and thus shaded from light. Typically there does not seem to be any expulsion of argillaceous matter on recrystallization and the rocks may be almost pure limestones. The partial recrystallization may be due to an original admixture of aragonite in the calcareous mud. X-ray analysis of the sediments brought back by the Meteor expedition has revealed the occasional presence of aragonite (up to 40 per cent) in the finest colloidal portions of shallow water samples (Correns, 1937). Data on the progress of the change can be obtained from the Funafuti Report (Cullis, 1904). Professor Cullis found many instances of the infilling of cavities by calcareous mud or precipitated material which might be either calcite or aragonite. From the deeper portions of the core he found that the aragonite was recrystallized while the calcite retained its original form. It appears probable that clotted limestones originate by partial recrystallization of such an originally heterogeneous mud. The " clots "—the material not recrystallized—often show the features of an algal dust.

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[1] The " very small oolites " mentioned by E. E. L. Dixon as one of the characteristics of the lagoon deposits of South Wales are in many cases faecal pellets.

[2] H. de Dorlodot (1909) used this term as an equivalent of the English " contemporaneous breccia ". Following him Vaughan (1915) and S. H. Reynolds (1921) spoke of " grumelous limestones ", but the term was not needed and has fallen into disuse. In Belgium L. Kaisin (1927) and in France L. Cayeux (1935) use the term to indicate a partially recrystallized limestone, as in the present paper. Since the term calcaire grumeleux in the sense of contemporaneous breccia is not needed I here use " clotted limestone " as the equivalent of calciare grumeleux in the modern French usage.

(*e*) *Pseudobreccias.* There is no definite boundary between clotted limestones and pseudobreccias. In the latter case the fragments are much larger, and the material not recrystallized forms a matrix lapping them round.[1] In both cases the characteristic features are probably due to recrystallization of an aragonite portion in the original mud, accompanied by somewhat concretionary aggregation of the recrystallized material.[2] When the recrystallization was complete and the whole rock was composed of calcite the previously stable matrix was now more susceptible to change than the fragments, owing to its smaller grain size (as already pointed out by Dixon). This difference in susceptibility seems to explain the fact that struck Dixon (1911); that the matrix had less foraminifera than the fragments. When a pseudobreccia is closely examined, foraminifera can be seen in the matrix as well as in the fragments. Those in the recrystallized fragments have their granular walls perfectly preserved, those in the matrix are more hazy and have suffered attack by dolomitization. Since the fine-grained matrix is especially liable to later replacement and recrystallization the foraminifera contained in it, whose walls consist of equally minutely granular calcite, become hazy in outline and may disappear, while those foraminifera bedded in the recrystallized fragments are sheltered and retain all their minute structure.

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[1] It should be noted that the " fragments " of pseudobreccias are not equivalent to the " clots " of clotted limestone. The Belgian geologists, working with the fine-grained clotted limestones, studied them in slide. The dark (i.e. unrecrystallized) portions were termed " clots ". Pseudobreccias are much more striking features and were studied first in the field and in hand specimens. Therefore the dark portions (= more translucent, i.e. *recrystallized* parts) were termed fragments or, in some cases, " clots."

[2] It is possible that the difference between pseudobreccias and clotted limestones arise because of the originally larger portion of aragonite mud in the former. Segregation was thus easier and the resulting recrystallized fragments are large.

No other details of importance can be added to the very full account of pseudobreccias given by Dixon.

(*f*) *Inclusions in Ooliths.* An algal limestone from the Windsor Series (Carboniferous Limestone) of Nova Scotia shows ooliths with a radial structure (Pl. II, Fig. 4). In the same slide occur *Pycnostroma*-like [1] aggregations of which a portion is visible on the side of the figure. Fragments of algal dust presumably derived from the *Pycnostroma* are common in the slide and are included in the ooliths. The dust appears to be mechanically enmeshed between the fibres which measure up to ·008 mm. broad in their outer portions and are elongated parallel to the *c* axis. It would appear that the algal dust was in suspension in the water while the ooliths were forming and during the recrystallization of these and the formation, or accentuation, of the radial structure, the dust retained its individuality. Owing to the tenuity of the dust which would render it prone to recrystallization it is probable that there was some physical difference between it and the calcium carbonate of the ooliths. Such inclusions of calcium carbonate " dust ", are common in the Carboniferous ooliths, forming dusky concentric and radial patches.

SOURCE OF THE LIMESTONE PASTE

It has now been shown that many lithological types of Carboniferous Limestone contain material closely resembling that precipitated by algae. Dixon has demonstrated (1911) that the fine-grained " chinastones " were most probably formed in shallow water. It is in shallow water that algae flourish and it s probable that they were widespread in the " lagoon phases ". *Ortonella* is found in the South Wales limestones (H.M.G.S.. slide E 3443), and Professor S. H. Reynolds has stated (1921, especially pp. 225–6) that algal remains are common in the Modiola (= lagoon) phases of the Avon section. Also microscope ections show (Pl. II, Fig. 4) that granular fragments of algal dust become detached and broken down. So there is a probability hat some at least of the finest grained material in Carboniferous Limestones was derived from algal precipitates. There is even ome indication from a comparison of recrystallization phenomena n clotted limestones and pseudobreccias with those in ooliths, hat there were two types of fine-grained sediment in the Carboniferous seas, one which behaved exactly as does algal ust, recrystallizing rather reluctantly, and one which ecrystallized freely. In any case the association of algal dust with ooliths (see above) goes far to show that, in some cases at least, chemical precipitates of calcium carbonate will not take up the same grain size and physical character as those precipitated by algal action.

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[1] Nomenclature as proposed by Pia (1927).

An evaluation of the exact parts played by chemical and bacterial precipitation, by comminuted shell matter, and by algal dust is impossible to make at present. There are too many unknown factors.[1] All that can be certainly stated is that algal dust has contributed in some measure to the formation of the Carboniferous Limestone. Later work may show it to have played a large part in the formation of certain beds. Whenever the limestone weathers china-white and appears fine-grained and structureless when broken, material similar to algal dust will be found in a thin section.

ENVIRONMENT AND DEPOSITION

The well known description of lagoon phases in South Wales by Dixon (1911) is so clear that only a slight amplification is necessary here. The deposition of the Modiola phases took place in a shallow probably relatively calm sea. Algae flourished and in periods of calm calcite mudstones were laid down. Scavenging creatures abounded and the pellets of the mud-eaters were heaped together in time of storm, forming, with crinoid fragments, ooliths, and the like a fragmental limestone. Occasional erosion of previously formed calcite mudstones also occurred and the fragments, rounded by attrition, were heaped together to make grain limestones. Naturally all transitions occur between these types. The action of scavenging animals would tend to break up and destroy shells, and only in the more rapidly deposited portions of the chinastones would fossils be plentiful. Even in these layers, however, the chief forms are lamellibranchs, ostracods, worm tubes, and calcareous algae. A standard marine fauna is lacking. The peculiar fauna of the Modiola phases is probably to be explained as due rather to the soft yielding character of the " calcite-mud " of which the sea bed was composed rather than to any connection with depth as such.

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[1] It may be mentioned that much of the finest grained material round modern coral reefs appears to be derived from the breaking down of madreporarian coral skeletons. This seems to be connected with the fact discovered by Sorby (1879) that aragonite shells may break down to an impalpable calcite paste. However in the Carboniferous period corals had apparently a calcite skeleton (Black in Hatch and Rastall, 1938), and mollusca, which have aragonite skeletons, were relatively rare.

In conclusion I wish to thank Mr. W. N. Edwards and Dr. C. J. Stubblefield for access to algal material under their care. Professor W. F. Whittard kindly sent on loan the Reynolds collection of rock slices, and Dr. J. Phemister has facilitated the loan of several of Dixon's slides, while Dr. A. Brammall has kindly read the paper in typescript. The specimens from Nova Scotia were obtained with the help of the J. B. Tyrrell Fund of the Geological Society of London.

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EXPLANATION OF PLATE II

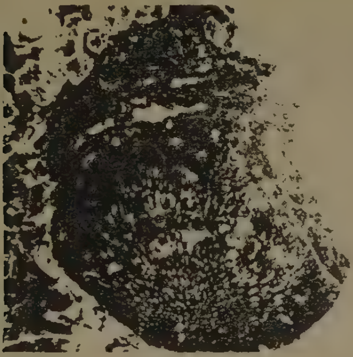
FIG. 1.—*Mitcheldeania* sp. Showing contrast in transparency between the algal precipitate and coarser grained calcite filling moulds of the algal filaments. Wilderness Qy., Forest of Dean. × 10.

FIG. 2.—Pellet Limestone. The material composing the pellets and trapped in the ooliths is very fine grained and similar to " algal dust ". Great Quarry, Avon Section. S 2. Reynolds coll. slide 119*a*. × 45.

FIG. 3.—Grain limestone. Grains of calcite mudstones (one composite) with rounded echinoderm fragments cemented by clear calcite in optical continuity. Lower Avonmouth line, Avon Section. Reynolds coll. slide A8. × 42.

FIG. 4.—Oolite grains with inclusions of algal dust. Algal limestone, bed D, Flux Quarry, Point Edward, Nova Scotia. × 52.

FIG. 5.—Clotted limestone inside gastropod shell, the whole coated by an algal precipitate. 8 feet below columnar limestone, Crawley Creek, Point Edward, N.S. × 34.



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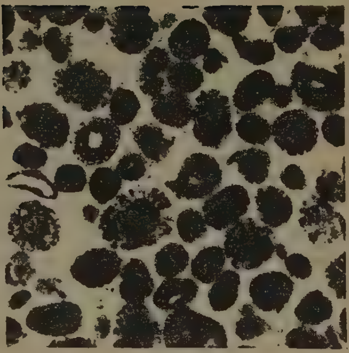

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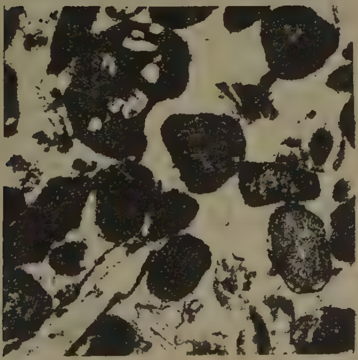

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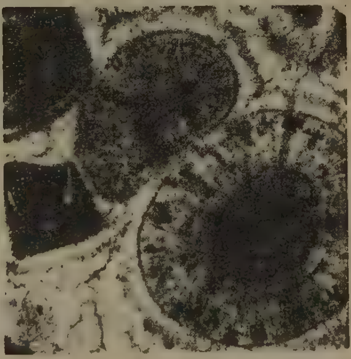

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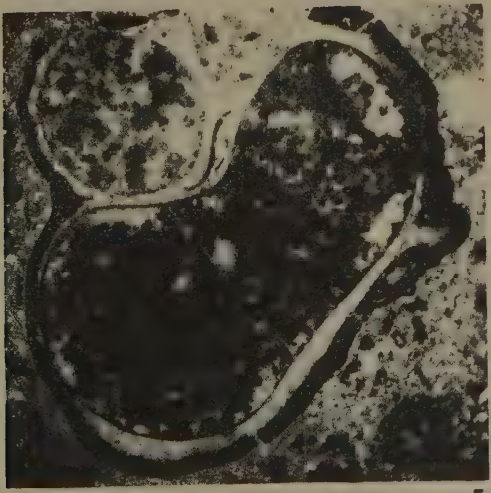

5

Algal Structures in Limestones.

The Carboniferous Limestone of Breedon Cloud, Leicestershire, and the associated Inliers

By G. H. Mitchell and C. J. Stubblefield [1]

1. Introduction

EIGHT inliers of Carboniferous Limestone are situated between Ashby de la Zouch and Melbourne on the north-eastern side of the Leicestershire Coalfield. They may conveniently be divided into a western group consisting of the Ticknall, Calke, and Dimminsdale exposures, all of which occupy comparatively low ground in valleys, and an easterly group, Breedon Hill, Breedon Cloud, Barrow Hill, Osgathorpe, and Grace Dieu. The first three of the latter group form prominent hills rising above the Triassic rocks which surround them. They are also remarkable for the high dips in the rocks composing them. In the other inliers dips of less than 15° are the rule, while dips of about 5° are common.

These rocks are mentioned in the Memoir describing Sheet 141 (Fox-Strangways, 1905), and also in the Coalfield Memoir dealing with the South Derbyshire and Leicestershire Coalfield (Fox-Strangways, 1907). In 1917 they were the subject of a paper by L. M. Parsons (1918). In these three accounts the geographical relationships and general appearance of the rocks are well described so that attention will here be directed to a new interpretation of the stratigraphical succession at Breedon Cloud together with supplementary remarks on several of the other outcrops. Parsons's chief conclusions were that all the limestones are of *Dibunophyllum* zone age [2]; that D_1 is developed at Breedon Hill and Breedon Cloud (*Productus humerosus* Beds), and that D_{2-3} occurs at these places as well as in the western inliers. The structure of Breedon Cloud was believed to be complicated by two reversed faults causing a double repetition of the whole sequence. In the present view this repetition is not supported by the mapping. Indeed the assumption of faulting appears to have led to a confusion of faunal content of the threefold subdivision accepted by Parsons (1918, p. 99).

In the case of Barrow Hill, Osgathorpe, and Grace Dieu, the quarries are now greatly overgrown and little can be added to the earlier descriptions. The present account is the result of work carried out during the recent revision of the South

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[1] Published by permission of the Director of H.M. Geological Survey and Museum.

[2] This view was challenged by Hind (1918) and later by Alexander (1934).

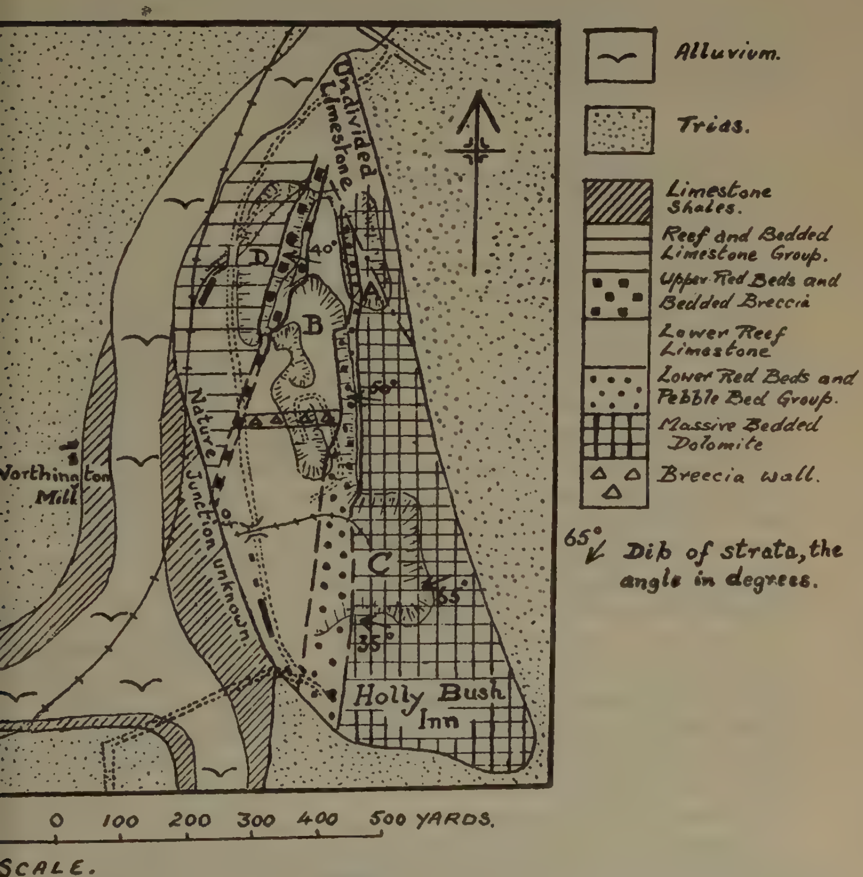
Derbyshire and Leicestershire Coalfields. The preliminary field work was conducted by the first named author; both authors combined in the detailed collecting of fossils, in which they acknowledge the assistance of Mr. R. V. Melville. To the Headmaster of Repton School they are indebted for the privilege of examining the Vassall Collection and to Miss H. M. Muir-Wood and to Professor H. H. Swinnerton for similar facilities with the British Museum (Natural History) and University of Nottingham collections respectively. Mr. P. E. Kent kindly accompanied us on one occasion in the field and was helpful in discussion. The ready access for the examination of exposures afforded by Mr. Godfrey Mosley, of Calke Abbey, by Mr. J. G. Shields, of Isley Walton, and the kindly co-operation of Mr. R. H. Walker, of Breedon Quarries, are much appreciated.

Thanks are also due to Dr. Stanley Smith who has named the corals and Mr. W. S. Bisat who has confirmed the naming of the goniatites. Otherwise the second author is responsible for the palaeontology.

2. BREEDON CLOUD QUARRY

At Breedon Cloud the hill has been extensively quarried. The older workings were situated on the western flank of the ridge and appear to have been based on a common quarry floor-level of approximately 300 feet O.D. This is the level of the present large workings at the southern end of the hill. The centre of the quarry area (C of map, Text-fig. 1) lies about 250 yards N.N.E. of the Holly Bush Inn. The eastern wall of these workings is at least 100 feet high. The quarry wall of the disused workings at this level extends in an irregular line northwards for some 500 yards and in places the old quarry floor still remains. More recently a new level has been opened some 40 feet below at about 260 feet O.D. The workings at this level are most extensive in the north (D of map, Text-fig. 1) where the old 300 ft. floor has been completely quarried away, while the same process is continuing rapidly in the central part of the area (B of map, Text-fig. 1). In addition a new quarry is fast being developed in the north-eastern part of the area on the eastern flank of the hill (A of map, Text-fig. 1). The floor here is also based on the level of approximately 260 feet O.D. A peculiar wall-like mass of breccia extends from east to west about the centre of the western quarries (south of B on map, Text-fig. 1), and though breached in its central portion by quarrying, still stands up in a striking manner on the sides of the quarry.

The approximate location of the quarries in August, 1940, is shown in Text-fig. 1. The general strike of the beds is almost north and south, while the prevalently high westerly dip may reach 65° or more.



G. 1.—Sketch-map of Breedon Cloud Quarries. The letters A to D refer to individual quarries mentioned in the text.

The Carboniferous Limestone Series is overlain unconformably by Triassic rocks of Keuper age, which on the eastern flank of the hill may well conceal a considerable pre-Triassic fault trending in a north-north-westerly direction.

The stratigraphical succession at Breedon Cloud is as follows :—

		Approximate thickness.
?	Limestone shales (fauna and relationships unknown)	
B_2	Upper Reef and Bedded Limestone Group with *Goniatites hudsoni-maximus* group and in lower beds *Davidsonina* [*Cyrtina*] *septosa transversa* . .	120 ft.
D_1	Bedded Breccia with *Davidsonina* [*C.*] *septosa* . .	3 ft.
D_1 ?	Upper Red Beds	up to 10 ft.
B_1 or S_2 ?	Lower Reef Limestone	120 ft.
C_2S_1	Lower Red Beds and Pebble Bed Group with *Cravenia rhytoides* and *Chonetes destinezi* . .	20 to 60 ft.
	Unconformity	
C_2	Massive Bedded Dolomites with *Productus* (*Plicatifera*) *humerosus*	235 ft. or more

(i) *Massive Bedded Dolomites.*—These are the beds most sought in quarrying operations and form the main mass of the southern (C of map, Text-fig. 1) and north-eastern (A of map, Text-fig. 1) quarries. They consist of thick-bedded yellow dolomites of which the lower 130 feet are granular and free from chert. The higher beds are usually fine-grained, clean fracturing yellow dolomites with chert strings and often carrying " vughs " filled with dolomite sand. They dip steadily westwards at high angles and show little other disturbance save at the north-eastern end of the quarries where they are traversed by a fault trending north-north-west. This fault appears to throw the Lower Reef Limestones against the Massive Bedded Dolomites on the western wall of the North-Eastern Quarry (A of Text-fig. 1).

The Fossils.—Except in the cherty beds towards the top of the sequence, the fossils are preserved as casts and moulds, the casts being often coated with small dolomite crystals. The fauna is restricted in species and is chiefly composed of brachiopods, though crinoid stem-columnals and indeterminate simple corals occasionally occur. The most characteristic fossils belong to the species-group of *Productus* (*Plicatifera*) *humerosus* J. Sowerby which as elsewhere (Paeckelmann, 1931, p. 121), exhibits considerable variation ; the typical form [1] is present as also several varieties including undescribed forms ; the variety *christiani* de Koninck has been found high in the division. Chonetids and Daviesiellas are not infrequent, and of these a fairly thick-shelled inflated form with ribbing more densely packed laterally than anteriorly has been compared with *Chonetes franconicus* Paeckelmann (Paeckelmann, 1930, p. 293, pl. 20, figs. 4*a*–*d*; pl. 21, figs. 1, 2), of which species, however, the internal characters are undescribed.

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[1] The type locality of *P. humerosus* given by J. Sowerby in the *Mineral Conchology*, iv, 1823, p. 21, pl. 322, is [Breden] Breedon ; this is likely to be Breedon Hill, where the fossil was formerly more readily collected, rather than Breedon Cloud—at the present time Breedon Cloud is an easier collecting locality.

This species was figured from Trogenau in the Frankenwald which is one of the German localities for *P.* (*Pl.*) *humerosus*. The Breedon Cloud material cannot rightly be claimed to show the generic characters of *Daviesiella* nor yet those of Cope's (1934) genus *Airtonia*; the evidence of the musculature and apical plates points to the genus *Chonetes s. str.* as interpreted in current Carboniferous palaeontology.

The fauna includes: Zaphrentid? coral, cf. *Athyris expansa* (Phillips), *Chonetes* cf. *dalmanianus* de Koninck, *C.* cf. *franconicus* Paeckelmann, *C.* cf. *münsteri* Paeckelmann, *Daviesiella notata* F. W. Cope, *Dielasma?*, *Productus* (*Plicatifera*) *humerosus* J. Sowerby also var. *christiani* de Koninck, var. *donicum* (Rotai), var. *plicata* Paeckelmann, cf. var. *plicata* and var. nov. 1 [a broad and deeply sinuate shell, probably the same form as one occurring at Reynard's Cave, Dovedale, Derbyshire] and var. nov. 2 [a wide-hinged variety]. The practice of Eccles *in* Davidson (1880, p. 306), Yanishevsky (1918, p. 129), and Paeckelmann (1931, p. 121) of considering *Productus sublaevis* de Koninck, 1842, as a synonym of *P. humerosus* J. Sowerby, has been followed here.

Despite prolonged search, neither *Davidsonina* [*Cyrtina*] *septosa* (Phillips) nor *Pugnax pugnus* (Martin) have been found in these beds. (Cf. Parsons, 1918, pp. 97, 99; Hind, 1918; Sibly, 1920.)

Vaughan (1915, p. 47) stated that at Clitheroe *P. sublaevis* (= *P. humerosus*) entered at the top of C_1 and formed a persistent band at the top of C_2—this is in accord with the work of Parkinson (1926, pp. 196, 208; 1936, pp. 324, 327). Although Vaughan included the Belgian *sublaevis* beds as the basal members of $\delta(C_2S_1)$ on his diagram (1915, facing p. 32), on p. 21 he was inclined to date the *sublaevis* fauna as "Lower C_2". It is gratifying to find that the characteristic Black Marble fossil of Denée and Sovet (Dinant), *Chonetes destinezi*, directly overlies the *P. humerosus* Beds of Breedon Cloud as inferred by Vaughan for the Belgian region (1915, pp. 18–19).

(ii) *The Lower Red Beds and Pebble Bed Group* (C_2S_1).—These beds consist of reddish purple-stained dolomitic limestones and shales. They contain many large crinoid stems and frequently carry dolomitized limestone pebbles and boulders up to 10 inches across. Certain beds have abundant pebbles of quartz and dolomite; accompanying these are other pebbles, green in colour and up to 2 inches across, perhaps of Charnian origin. Corals and brachiopods are present in some numbers. The pebbly beds have been followed from a point 550 yards N. 3° E. of the Holly Bush Inn, southwards to the margin of the large quarry C. Here they are lost beneath the quarry floor. The finest exposure is probably that on a bare bedding plane 480 yards N. 4° E. of the Holly Bush Inn. On this surface large crinoid stems are intermingled with quartz and rounded dolomite pebbles with chips of green grits and ashes (probably Charnian) standing out prominently from a reddened dolomite matrix. Simple corals also occur. Other exposures show an abundance of dolomite pebbles several inches across and well rounded. In the northern part of the quarries the thickness of these beds probably does not exceed 15 feet, though reliable measurements are difficult to obtain.

The pebbly beds reappear on the southern wall of the quarry C (Text-fig. 1) and are here much thicker. At least 100 feet of beds were measured, consisting of well-bedded crystalline dolomites with purple and grey shale partings and large crinoid stems on the bedding planes. Quartz pebbles were noted scattered in the dolomites for about 76 feet up from the base. A large colony of *Diphyphyllum* near *lateseptatum* up to 3 ft. 3 in. across was seen 40 feet above the base and a mass of *Syringopora ramulosa* 2 feet across, about 30 feet from the base. Simple corals are rare at this exposure, but a *Cravenia* was found 2 feet from the base.

The Fossils.—In this group the echinoderm remains usually persist in the condition of calcite, but the other invertebrate fossils are mostly replaced by dolomite and stand out well on surfaces from which shaly beds have been weathered. The most remarkable fossil of the group is the largest in size ; it is a geniculated brachiopod shell preserved in opaque yellow dolomite with a thick and spinose hinge-line 21 cm. (8¼ inches) or more in length and with a shell up to 1 cm. in thickness. Large diverging flabellate ventral divaricator muscle-scar extend almost to the geniculation and for about half their length are bounded on the inner sides by a pair of adductor scars and in front of these by elevated ridges separated from each other by a median groove. This form is identified as the species named *Chonetes destinezi* by Vaughan (1915, p. 46) who called attention to its development in Belgium (Sovet and Denée, both near Dinant), Clitheroe, Arnside,[1] and in the Stack region of Pembrokeshire in C_2 or (C_2S_1) strata.[1] See also Delépine, 1928, p. 17, pl. v, fig. 54.

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[1] The Arnside occurrence, however, probably refers to *Daviesiella carinata* Garwood which is now regarded as a distinct species (Cope, 1935). *C. destinezi* occurs, however, in C_2S_1 beds at Moorbank Mines in S.W. Cumberland.

Corals are prominent members of the fauna of this group, notably *Cyathaxonia rushiana* Vaughan and *Cravenia rhytoides* Hudson; these species are prevalent in the central exposures whilst megastomid *Michelinia*, giganteid *Caninia* and occasional *Lithostrotion* occur in the more northerly portion of the outcrop.

Cravenia rhytoides was originally described from δ Beds (C_2 conglomerate) of the Craven Lowlands (Hudson, 1928) and according to Miss Hill (1938, p. 5) the species is not recorded from England after C_2 times.

The brachiopods and corals leave no doubt that these beds are of C_2 or C_2S_1 (δ) age. A few of the fossils are fragmentary, others are well-preserved, a feature which is noticeable in some of the larger fossils, e.g. *C. destinezi*. No specimens of the *P. humerosus* fauna have been collected from these beds and it has not been found possible to affirm that any member of this fauna is remanié, despite the dominant dolomitic preservation of its members.

The fauna includes: *Caninia* near *C. gigantea* Michelin, *Cladochonus crassus* McCoy including *bacillarius* forms, *Clisiophyllum* sp., *Cyathaxonia rushiana* Vaughan, *Cravenia rhytoides* Hudson, *Lithostrotion irregulare* Edwards and Haime, *L.* {*Diphyphyllum*} near *lateseptatum* McCoy, *Michelinia* near *megastoma* (Phillips), *Palaeosmilia* sp. [slender form with narrow minor septa], *Zaphrentis* near *konincki* Edwards and Haime—Carruthers, *Z.* near *omaliusi* Edwards and Haime; Crinoid remains including *Platycrinus* sp.; *Archaeocidaris* sp., *Palechinus?*; *Fenestrellina* sp., *Rhabdomeson* sp.; *Brachythyris?*, *Chonetes destinezi* Vaughan, *Cleiothyridina glabistria?* (Phillips), *C. hibernica* (Douglas), *C.* sp. nov. [a wide shell, not sinuate], *Orbiculoidea* sp., Cf. *Productus* (*Echinoconchus*) *punctatus* (Martin), *P.* (*Dictyoclostus*) cf. *vaughani* Muir-Wood, *Punctospirifer* sp., *Rhipidomella michelini* (Léveillé) [including large forms], *Schizophoria resupinata* (Martin) [including large forms], *Spirifer* cf. *bisulcatus* J. de C. Sowerby, *S.* cf. *furcatus* McCoy, *S.* cf. *semicircularis* Phillips, *Spiriferellina octoplicata* J. de C. Sowerby mut. δ Vaughan; cf. *Griffithides? carringtonensis* H. Woodward; ? *Psephodus magnus* Agassiz.

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[1] More recently T. N. George and D. R. A. Ponsford ("Mid-Avonian Goniatites from Gower," *Ann. Mag. Nat. Hist.* [**10**], xvi, 1935, 354–370, pl. xi) have found a goniatite fauna at Caswell Bay, Gower, which is associated with *C. destinezi* and corals; they suggest that the goniatites may represent the IIγ or more probably the IIδ horizon of the German sequence (*op. cit.*, 369).

The Unconformity Between C_2S_1 and C_2 Beds.—The presence of pebbles within the C_2S_1 beds immediately suggests a stratigraphical break, and it is a matter of some satisfaction that two sections appear to support this suggestion. The more northerly section is situated at the north-western corner of quarry C (Text-fig. 1). Here high up in the quarry face it was possible in August, 1940, by clambering over quarry-debris, to observe the following section :—

	ft.	in.
Pebble bed with quartz and dolomite pebbles carrying *Cyathaxonia rushiana*, *Cravenia rhytoides* and *Chonetes destinezi* . . .	6	0
Reddish purple shale		3
Reddish purple dolomite with *Orbiculoidea*	1	4
Reddish purple shale with yellow dolomite pebbles up to ¾ in. across		9

These beds dip at 40° in the direction N. 60° W. and rest on thick-bedded yellow dolomites forming the highest beds of the Massive Bedded Dolomites which yield *Productus humerosus* and its variety *plicatus*. A reading taken in the lower beds a few yards away gave a dip of 55° in the direction N. 75° W. The lowest shale of the upper beds appears to wrap round slight projections in the underlying dolomites.

Another section was observed on a small shelf at the south-western end of quarry C (Text-fig. 1), 140 yards N. 18° E. of the Holly Bush Inn. Here the thick-bedded yellow dolomites with chert are somewhat disturbed, but resting on their broken edges and dipping steadily at about 35° slightly north of west are reddish stained dolomites with shale partings. Quartz pebbles are scattered at intervals throughout a thickness of about 76 feet of beds.

It seems likely that the photograph given by Parsons (1918, pl. ix) actually shows this unconformity and that the section is not faulted as there suggested. There are no signs of brecciation or movement which could be attributed to a fault, but the sections show closely welded junctions.

(iii) *The Lower Reef Limestones* (B_1 or S_2 ?).—Along the eastern wall of the quarry B (Text-fig. 1) these beds are seen to rest on the Pebble Bed Group. They appear to follow the latter abruptly and their white weathering is in marked contrast to the red and shaly nature of the preceding beds. They may be followed for some 430 yards in the central portion of the quarries before becoming lost below quarry tips at their southern limit. About 550 yards N. by W. of Holly Bush Inn an included thin bed of reddened shale or dolomitic mud shows sharp folding. Where fresh the rock is a yellow dolomite, compact and splintery, sometimes mottled pink. Pockets of dolomitic sand occasionally occur, while brecciation is a feature in places. There are only occasional traces of bedding and the appearance of the rock recalls that of a reef limestone. The subsequent dolomitization has destroyed or defaced many of the fossils.

The Fossils.—These are largely moulds and casts and a well-ribbed Camarotoechid is probably the most common. Spiriferids and a *Lithostrotion* near *L. martini* Edwards and Haime also occur.

A single goniatite (1·2 mm. in diameter and about 8 mm. thick, with a small umbilicus and four well-marked constrictions in rather more than half a whorl) bearing some resemblance to *Beyrichoceras hodderense* Bisat was found associated with *Pugnax pugnus* (Martin) in a yellow mottled matrix, but the specimen was imperfectly preserved and no reliance can be placed on the naming.

" *Cyrtina* " *carbonaria* McCoy has been recorded from Breedon Cloud (Kitchin, F. L., *in* Fox-Strangways, 1907, p. 13) and might reasonably have been expected to occur in these beds, but the Vassall Collection specimen which gave origin to the record has been cleaned of matrix and proves to be a *Spirifer* and probably came from a higher horizon. No diagnostic fossil having been collected, we are unable to assign zonal connotation to these beds but we suggest tentatively that they may be of B_1 or S_2 age. The correlation of B_1 with S_2 rests principally on the association of the *Beyrichoceras hodderense* zonal assemblage with *Davidsonina* [*Cyrtina*] *carbonaria* (McCoy) found and communicated to us by Mr. G. B. Alexander near Calton Moor in Staffordshire.

Fauna.—*Lithostrotion* near *martini* Edwards and Haime, *Microcyathus cyclostoma* Phillips ; Crinoid remains ; *Camarotoechia* cf. *trilatera* (de Koninck), *Martinia* cf. *glabra* (Martin), *Phricodothyris ?*, *Productus* (*Thomasina*) sp., *Pugnax pugnus* (Martin), *Rhipidomella michelini*, *Schuchertella* sp., *Spirifer* cf. *striatus* Martin ; *Leiopteria ?* ; cf. *Beyrichoceras hodderense* Bisat.

The wall-like mass of breccia mentioned earlier is taken to belong to this group of beds. The relation which it bears to rocks lying west of it cannot be observed owing to quarry-debris, but it clearly cuts the reef limestone with nearly vertical bounding walls. The eastern margin is tolerably well-exposed. Here the breccia, which is dolomitized throughout, rests on the red-stained dolomite and shale beds of the Pebble Bed Group, but nowhere is it seen to cut them. Indeed, higher up the quarry and consequently up the dip slope of the Pebble Bed Group, there is no sign of the Breccia. Furthermore the bedding planes of the Pebble Bed Group extend right across the course of the breccia with a break of no more than about a yard of grass-covered slope. There is no sign of a fault affecting the Pebble Bed Group. If such a fault does exist at the grass covered patch mentioned above, it must be a tear with movement almost exactly directed along the bedding planes. The explanation here put forward is that the breccia marks a channel in the reef mass which was subsequently filled by breccia eroded from the reef. The dolomitization renders useless a comparison of breccia fragments with those of other neighbouring rock types.

(iv) *Upper Red Beds* (D_1 ?).—The importance of these beds lies not in their thickness but in the contrast which their appearance presents when compared with the beds above and below them. They do not exceed 10 feet in thickness and consist of red-stained thin-bedded dolomite. Though it cannot be proved it appears probable that these beds rest with some discordance on the Lower Reef Limestone. As seen in the northern wall of quarry B (Text-fig. 1) the red shale thins out eastwards when traced up the quarry face.

(v) *Bedded Breccia* (D_1).—This distinctive band of dolomite breccia is noticeably bedded, white weathering but yellow on broken surfaces. The breccia fragments reach 2 or 3 inches across and the rock is richly fossiliferous with corals and brachiopods forming the bulk of the fauna. Dolomitization has frequently partially or wholly destroyed the fossils.

The Fossils.—This fauna is chiefly found as dolomitic replacements; associated with *Davidsonina* [*Cyrtina*] *septosa* (Phillips) are thick-shelled giganteid Productids which compare with forms represented in the Alexian division of the Oksian (C_1Al_1 or C_1ok.al.) of the Moscow Basin where also occurs the typical "*Productus*" *semiplanus* Schwetzoff (Sarycheva, 1918, p. 63).

The fauna includes *Caninia* aff. *C. juddi* (Thomson), *Carcinophyllum ?* [possibly *C. vaughani* Salée], *Clisiophyllum keyserlingi* McCoy, *Cyathaxonia rushiana* Vaughan, *Lithostrotion* sp. [near *L. junceum* Fleming but large and approaching *L. irregulare* auctt.] *L. martini*, *Syringopora* sp.; Porifera undetermined; *Fistulipora* sp.; *Composita ?*, *Davidsonina* [*Cyrtina*] *septosa* (Phillips), *Daviesiella ?*, Orthotetid, *Martinia ?*, *Productus* (*Plicatifera*) *plicatilis* J. de C. Sowerby, *P.* (*Echinoconchus*) *punctatus*, *P.* (*Pustula*) *pustulosus ?* Phillips, *P.* (*Gigantella*) cf. *striatosulcatus* Schwetzoff var. *janischewskii* Sarycheva,[1] *P.* (*G.*) *giganteus* (Martin) var. *inflata*

Sarycheva,[1] *P.* (*Eomarginifera*) cf. *triquetrus* Muir-Wood, "*P.*" cf. *semiplanus* Schwetzoff, *P.* (*Linoproductus*) sp., *P.* (*Thomasina*) sp. *Pugnax* cf. *raricosta* (Phillips), *Spirifer bisulcatus* J. de C. Sowerby; *Naticopsis* sp.; Orthocone nautiloid; *Griffithides?* cf. *carringtonensis*.

Despite the reported occurrence of *D.* [*C.*] *septosa* from D_2 strata in co. Clare (Douglas, 1909, p. 556),[2] the association of this species here with the *Lithostrotion* species is not inconsistent with a D_1 zonal horizon being assigned to this fauna (Garwood, 1912, p. 478, Dixey and Sibly, 1918, p. 148, Dixon, 1921). Further work is, however, required before the horizon-marking value of some members of the fauna can be properly assessed.

(vi) *Reef and Bedded Limestone Group.*—Beds of this group are confined to the north-western portion of quarry D (Text-fig. 1). Owing to quarry-debris between them and the strata below, no good junction is visible. These, the highest Carboniferous Limestone beds exposed in the quarries, are well-jointed dolomites in which bedding is only occasionally seen. Where bedded limestone does occur it passes laterally and insensibly into unbedded limestone. Both unbedded and bedded varieties of limestone are usually compact, and even splintery in appearance, but the unbedded type bears a close resemblance to reef-limestone. Fossils are frequent, being often preserved as hollow moulds. The brachiopods include *D. septosa* in the lower beds, while large masses of colonial corals and occasional goniatites were collected from the higher beds. Some red and yellow marl inclusions may be a foot or two across and themselves contain dolomite in rounded balls. The dolomitization is marked and further obscures the character of the beds.

The Fossils.—At the northern end of the north-western quarry (D of Text-fig. 1) *Davidsonina septosa* is fairly easily found in an exposure north of the track to the quarry 'screens' (800 yards N. by W. of the Holly Bush Inn). Here it is associated with *Lithostrotion* sp., thick-shelled strongly arched Gigantellid Productids, *Pugnax* sp. and *Spirifer* cf. *bisulcatus*. The shell, however, has been dissolved away to leave casts and moulds rather in the condition of the specimen no. 62654 preserved in the

[1] Though not as well-preserved, these specimens compare well with the excellent illustrations of these varieties given by M. E. Janiševskij (1926, pl. iii, figs. 1, 3, 4) under the name of *P. giganteus* var. *gibbosa* later renamed as above. The Breedon Cloud form here compared with var *janischeuskii* has a highly vaulted venter and well differentiated ears. In Novaya Zemblya these Productids seem also to be associated with *D.* [*C.*] *septosa* (Janiševskij, 1926).

[2] We are indebted to Mr. W. S. Bisat for drawing our attention to this Irish record.

Geological Survey Museum collected by R. Gibbs in 1855 from 'near Ashby de la Zouch probably Breedon' and figured by Davidson (1859, pl. xiv, fig. 9). Since the species is not known from Breedon Hill, it is probable that Gibbs' specimen came from this horizon at Breedon Cloud. Forms resembling the variety *transversa* J. W. Jackson (1922, p. 468), a transverse form with a median ventral sinus and dorsal fold, were found with the more typical form.

On the north-west side of the same quarry and slightly higher in the succession a *Gigantella* over 20 cm. (8 inches) in width has been collected which resembles McCoy's *Productus maximus*. The original description of the species (McCoy, 1844, p. 112) states that it frequently attains a width of one foot. In the later edition of McCoy's work (McCoy, 1862, p. 231) Griffith records that *P. edelburgensis* Phillips occurs at the locality given for *P.* (*G.*) *maximus*, though there is no statement that they are present in the same bed. A coarsely ribbed *Gigantella* resembling Phillips' species is, however, found near *P.* (*G.*) *maximus* at Breedon Cloud.

By the railway-arch on the north-west side of the quarry, an immature globose goniatite [20 mm. in diameter and 17 mm. thick] was collected which is probably a young stage of a member of the *Goniatites hudsoni* Bisat—*G. maximus* Bisat group, such as is represented by a specimen [50 mm. diameter and 38 mm. thick] in the Breedon Cloud Collection of fossils made under the guidance of H. Vassall and now preserved in Repton School Museum. Another goniatite in that same collection [39 mm. diameter] approaches *Prolecanites discoides* Foord and Crick. These specimens are sutured internal casts, and there are grounds for thinking that they occurred associated at Breedon Cloud, since a few years ago Mr. E. W. J. Moore presented to the Geological Survey Museum [Nos. 59505–9] a similar goniatite fauna represented by the same two species from B_2 strata 30 to 40 feet below the local base of P_1 Beds in Higher (or Cowdale) Clough 2 miles west of Barnoldswick.[1]

It has not been possible to demonstrate any stratigraphical break between the strata yielding *D. septosa* var. *transversa* and the slightly higher beds containing B_2 goniatites. The range of strata are therefore assigned to B_2 age. This should not be taken to infer that the writers equate B_2 with D_1. There is a distinct possibility that *D. septosa* var. *transversa* is indicative of an horizon higher than that of the *C. septosa* Band of the North-West Province and Derbyshire, and of the South Welsh occurrences. In this connection it is noted that Jackson's variety was stated (1922, *loc. cit.*) to occur in the "Brachiopod Beds" of Park Hill, Middle Hill near Castleton, Derbyshire, and of Narrowdale, Staffordshire. The knoll-reef limestones of Middle Hill have lately been assigned by Shirley and Horsfield to B_2 age (1940, p. 278, and pl. xviii) though they make no mention of the occurrence of var. *transversa* in this B_2 fauna. Garwood and Goodyear (1924, p. 239) record "*C.* '*septosa*' Phillips very transverse form" from knoll-reef limestones of the High Hills, Settle and Stockdale Gorge, Scaleber. This fossil is listed as a member of a fauna which, from the goniatite evidence, must contain some elements of B_2 or P_1 age. Finally it should be added that this transverse form of *D. septosa* was figured by de Koninck (1843, p. 255, pl. xii bis, fig. 5 as *Spirifer subconicus* Martin) from Visé. At Visé, according to Vaughan (1915, p. 31), "There is nothing [in the Carboniferous Limestone] as low as D_1," and the limestones were compared by him with the Brachiopod Beds of the Midlands and with the Cracoe Knolls.[1] The fauna of those strata overlying the *D. septosa* var. *transversa* beds includes :—

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[1] Mr. Bisat, to whom the Breedon and Cowdale Clough specimens have been submitted for comparison and comment, writes that he can see little if any definite morphological difference between the two suites.

Clisiophyllid coral, *Lithostrotion* near *junceum* Martin [large form] ; *Athyris expansa* Phillips, *Camarotoechia* sp., *Martinia* cf. *glabra* (Martin), *Productus* (*Gigantella*) cf. *edelburgensis* Phillips, *P.* (*G.*) *maximus* McCoy, *P.* (*Eomarginifera*) cf. *triquetrus*, *P.* (*G.*) sp. [thin-shelled form], *Pugnax* cf. *raricosta* (Phillips) ; Bellerophontids, *Naticopsis* sp. ; cf. *Vestinautilus crateriformis* Foord.

It is probable that the Breedon Cloud latissimoid Productids in the Repton School Collection came from this horizon but no Breedon Cloud specimens of *P.* (*Gigantella*) *giganteus forma typica* have been seen.

(vii) *Limestone Shales.*—The details of the upper limit of the Carboniferous Limestone near Breedon Cloud are unknown. Dark shales occur, ½ mile S.W. of Worthington Station, west of the quarries but are separated from the Reef and Bedded Limestone group at the quarries by an area with no exposures.

Conclusions.—The zonal sequence of beds at Breedon Cloud Quarries ranges from C_2 to B_2 in the Carboniferous Limestone. The lowest or *P. humerosus* Beds are separated by a marked unconformity from the overlying C_2S_1 beds. The break is emphasized by a pebble bed series which affords evidence of erosion. A further stratigraphical break may occur between D_1 strata and those of B_2 age though no lithological break could be proved.

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[1] It should be noted, however, that the type specimen of *Productus sublaevis* was stated by de Koninck (1842, p. 158) to come from Visé ; until the stratigraphy of Visé is reinvestigated, the age of the beds there should best be considered *sub-judice*.

3. BREEDON ON THE HILL

The zoning of the beds in the large quarry at Breedon on the Hill has not been greatly advanced by the re-examination of this section. The *Productus humerosus* beds extend over a thickness of at least 300 feet and in places are quite fossiliferous while the higher beds forming the north-western wall of the quarry and isolated exposures on the hillside beyond have yielded little palaeontological information. The brecciation of these beds is often noticeable but their exact position in the sequence remains uncertain.

The fossils from the *P. humerosus* Beds are casts and moulds and include: Indeterminate corals; Crinoid stem-columnals; *Chonetes* cf. *franconicus* Paeckelmann, *C.* cf. *münsteri* Paeckelmann, *Productus* (*Plicatifera*) *humerosus* J. Sowerby, *P.* (*Pustula*) cf. *interruptus* I. Thomas, *Schizophoria resupinata* (Martin) and cf. var. *lata* Demanet, *Spirifer* cf. *semicircularis* (Phillips); *Grammatodon* cf. *semicostatus* (M^c^Coy) and *Grammatodon* sp. [? cf. *G. obtusus* (Phillips)]; *Bellerophon* spp. [one form possibly of *B. hiulcus* J. de C. Sowerby group] ? *Phanerotinus cristatus* (Phillips). On the east side of the hill overlooking the road a chert lenticle contained foraminifera, suggestions of sponge spicules, and ostracods.

A specimen of *Michelinia* near *M. megastoma* (Phillips) was collected loose from the quarry-floor 145 yards from the E.S.E. corner of the quarry and may possibly have come from the *P. humerosus* beds.

4. BARROW HILL

This quarry is greatly overgrown but such exposures as remain are reminiscent of reef limestone, though the dolomitization is severe. There is an old working at the extreme eastern edge of the exposure in which a coarse Triassic basal breccia rests on about 7 feet of fossiliferous quartzose grit somewhat purple in colour. In these, the lowest beds exposed, the following fossils have been recognized.

Chonetes cf. *franconicus* Paeckelmann, *Schizophoria* sp., *Spirifer* sp., and indeterminate gastropod and lamellibranchs. The presence of *C.* cf. *franconicus* suggests that these beds are of *P. humerosus* Beds age, and the preservation of the fossil is similar to a type seen at Breedon Cloud.

5. GRACE DIEU

The important feature about this heavily overgrown quarry is that it shows a large amount of bedded breccia suggesting deposition in shallow water and fragmental material perhaps formed near a shore line. In view of the proximity of Charnwood Forest and the known thinning of Carboniferous Limestone proved in the Desford Stocks House Boring this is significant (Fox-Strangways, 1907, p. 347).

6. CALKE PARK AND DIMMINSDALE

A prolonged search of the " Limestone Shales " of Dimminsdale Quarry failed to reveal any fossils, but an interesting feature is that at the base of these beds a thin pebbly grit with quartz pebbles rests on the Carboniferous Limestone. A section showing the same features is seen in Calke Park, 530 yards N. 73° W. of Calke Abbey. These sections may be of considerable importance in view of the increasing evidence of an unconformity between the Carboniferous Limestone and Millstone Grit Series in the Pennine region.

The old quarry 300 yards E.S.E. of Calke Abbey yielded foraminifera including species of *Endothyra* and *Orobias* ; the corals *Chaetetes depressus* (Fleming), *Syringopora reticulata* Goldfuss ; crinoid debris and numerous specimens of *Productus* (*Gigantella*) *giganteus* (Martin) var. *typica* Sarycheva and probably also var. *crassa* (Martin) ; from another old quarry, on the north side of Mere Pond and at its eastern end, were collected *Syringopora reticulata* ; *P.* (*G.*) *giganteus* var. *crassa* and var. *inflata* Sarycheva, *P.* (*Thomasina*) cf. *margaritaceus* Phillips and " *P.*" cf. *semiplanus* Schwetzoff. Dolomitic beds lying below the basal grits of the limestone shales are exposed in an old quarry 100 yards north of the east end of Betty's Pond, which is $\frac{1}{3}$ mile N.N.W. of Calke Abbey, and contain casts of a *Productus* which resembles " *P.* (*Gigantella*) n. sp. 2 aff. *gigantoides* " Paeckelmann as figured by Paeckelmann (1931, pl. 30, fig. 2) from III*a* beds of Hausdorf, Silesia, as well as *P.* (*G.*) *latissimus* J. Sowerby var. *prisca* Sarycheva.

7. TICKNALL

The subdivisions recognized by Parsons (1918, p. 88) appear to hold, though additional collection of fossils has yielded a number of interesting details. The lowest beds as exposed at The Caverns and in old quarries to the west are strongly current-bedded to an extent reminiscent of some Millstone Grits of the Pennine area.

The section as described by Parsons is as follows :—

	ft.	in.
Millstone Grit		
Shales passing up conformably into Millstone Grit . . .	30	0
Grey and yellow dolomites	11	0
Thinly bedded limestones with swarms of *Producti* and interbedded shales (" *Productus* Limestones ")	11	0
Sandy stratum	2	0
Foraminiferal limestones and shales	14	0
Crinoidal limestones with thin shaly partings (base not seen) .	10	0

The fossils from the " Crinoidal limestone and shales " include : *Dibunophyllum bipartitum* (M^{c}Coy), *Zaphrentis enniskilleni* Edwards and Haime ; *Platycrinus* sp., *Poteriocrinus* sp. ; *Productus* (*Gigantella*) *giganteus* Martin var. *typica* Sarycheva, *P.* (*Dictyoclostus*) *pugilis* Phillips.

The " *Productus* limestones " have yielded *Productus* (*Gigantella*) *giganteus* var. *typica* also var. *inflata* Sarycheva, *P.* (*G.*) *striatosulcatus* Schwetzoff var. *typica* Sarycheva, *P.* (*G.*) *latissimus* J. Sowerby cf. var. *complicata* Paeckelmann and in the topmost foot of this division, the foraminifera *Endothyra crassa* Brady and *Tetrataxis conica* Ehrenberg have been recognized.

From the dolomites overlying the *Productus* beds have been collected *Zaphrentis enniskilleni* ; Crinoid stem-columnals ; *Dielasma* sp., *Productus* (*Dictyoclostus*) cf. *antiquatus* J. Sowerby, *P.* (*Overtonia*) *fimbriata* J. de C. Sowerby, *P.* (*G.*) *giganteus* cf. var. *inflata*, *P.* (*G.*) cf. *striatosulcatus* var. *typica*, *Schizophoria* sp., *Spirifer* cf. *bisulcatus* J. de C. Sowerby and fragments of a large Nautiloid.

Additional to the species mentioned above, the tip-heaps from the beds below the dolomites harbour a rich fauna including a foraminifer resembling " *Bigenerina* " *triticum* Jones, *Endothyra bowmani* Phillips, *Orobias radiata* (Brady), *Palaeotextularia* sp. ; *Caninia juddi* (Thomson) emend. Lewis, *Caninophyllum archiaci* (Edwards and Haime) *halkynense* " type " H. P. Lewis, *Chaetetes septosus* (Fleming), *Dibunophyllum* sp., *Koninckophyllum* sp. *Lithostrotion junceum* Fleming [with some radiciform connecting processes], *Nemistium edmondsi* S. Smith,[1] *Zaphrentis* cf. *constricta*

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[1] This specimen was collected by Dr. J. Pringle in 1903 and was formerly named *Lithostrotion irregulare* Phillips ; the previous record of *Lonsdaleia floriformis* (Parsons, 1918, Kitchin *in* Fox-Strangways, 1907, p. 12) is now renamed ? young *Dibunophyllum*.

Carruthers ; Echinoid spines, Crinoid stem-columnals ; Polyzoa including *Fistulipora minor* M^cCoy ; *Actinoconchus planosulcata* (Phillips), *Athyris* cf. *lamellosa* (Léveillé), *Brachythyris decora* (Phillips), *B. integricosta* (Phillips), *Chonetes* (*Plicochonetes*) sp. nov., *C.* (*Tornquistia*) sp., *Cleiothyridina royssii* (Davidson), *Dielasma* sp., *Phricodothyris lineata* (Martin), *Productus* (*Dictyoclostus*) *antiquatus*, *P.* (*Gigantella*) cf. *auritus* (Phillips), *P.* (*P.*) aff. *concinnus* J. Sowerby, *P.* (*G.*) aff. *gigantoides* Paeckelmann, *P.* (*G.*) *latissimus* var. *prisca* Sarycheva, *P.* (*Thomasina*) cf. *margaritaceus* Phillips, *P.* (*G.*) cf. *moderata* Schwetzoff, *P.* (*Avonia*) cf. *ratingensis* Paeckelmann, *P.* (*Linoproductus*) cf. *striatus* Fischer, *P.* (*Eomarginifera*) cf. *triquetrus* Muir-Wood, *Rhipidomella michelini* (Léveillé), *Schizophoria resupinata* (Martin) and some of the fish-remains listed in Fox-Strangways (1907, p. 14).

In the Vassall Collection there are corals from these beds which include *Aulophyllum fungites* (Fleming), *Caninia* near *cornucopiae* Michelin and *Palaeosmilia murchisoni* Edwards and Haime, also two solidly preserved goniatites in dark matrix labelled Ticknall. The latter have been determined as *Goniatites crenistria* Phillips and *Beyrichoceratoides truncatum* (Phillips). If these are correctly localized it would seem that the P_{1a} zonal horizon is represented at Ticknall but in the absence of confirmatory evidence it would be hazardous to affirm from which strata they were collected, i.e. from above the dolomites or from below.

It seems reasonable to suppose as did Parsons (1918, p. 93) that the Ticknall succession is akin to that of the Calke inlier. Unfortunately the exact position in the local succession of the Ticknall goniatites is unknown ; it is therefore difficult to assess the age-relationship of the western (Ticknall and Calke) beds and those of Breedon Cloud. Certainly no evidence of a D_1 fauna has been found in the western inliers either by Parsons or the present writers. From the faunal content one is tempted to infer that the strata there exposed are younger than the B_2 beds at Breedon Cloud. Further detailed studies are required, however, on the description and ranges of the Productids, particularly of the Gigantellids, in western Europe before the application here of a zonal scheme based on these forms is warranted. Such work, chiefly on the Gigantellids, in the Moscow basin has yielded promising results (Sarycheva, 1928, p. 63) though even there, the relation of the succession to goniatite zones is as yet obscure.

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[1] These dates of publication are those given by C. D. Sherborn, "*Index Animalium*, 1801–1850," Section II, 1922, p. lxxv.

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A Collection of Carboniferous Limestone Fossils in the Skipton Museum

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RECENTLY I have had the opportunity of working through a large collection of Lower Carboniferous fossils, of which there appears to be no record in geological literature. The collection was made by R. H. Tiddeman from the district between Pateley Bridge and Settle, and is now in the care of the Skipton Museum. The bulk of the collection was probably made between 1890 and 1900 and has hardly been touched since.

There are over 15,000 specimens in the collection. About 120 of them are mounted on ground glass slips and were probably intended for exhibition at the British Association meeting at Bradford in 1900. From the general character of the assemblage it appears that most of the specimens came from the Craven Reef Belt, in which Tiddeman was particularly interested. Unfortunately precise localities are not known.

Apart from the great number of specimens, and their historical interest, the collection is notable for the perfection of the material; practically every specimen is free from matrix and in excellent state of preservation.

It has not been found possible in the time available to name all the species in the collection. Certain groups, the literature of which is reasonably compact, have been studied fairly carefully. This will be evident from the notes which follow, in which determinations must be regarded as provisional in many cases, pending more detailed study. A very brief account will be given of the scope of the collection, referring to specimens of interest in each phylum.

ARTHROPODA

Trilobites are relatively rare.

ECHINODERMATA

Blastoidea.—Five well preserved specimens of *Codaster* sp.

Crinoidea.—There are thirteen calices including beautiful specimens of *Amphoracrinus*, *Platycrinus*, and *Actinocrinus*. There are also innumerable stem ossicles.

Bryozoa.—Absent. Dr. Raistrick suggests that G. R. Vine, a personal friend of Tiddeman, may have taken them over, but search among Vine's publications and in the collection of Bryozoa in the British Museum (Natural History) has failed to confirm this.

MOLLUSCA

Gastropoda

A very extensive collection, beautifully preserved. The only group which has been carefully examined and named is the Bellerophontidae. There is a surprising number with well preserved ornament. The commonest are *Bellerophon tenuifascia* J. de C. Sow., and *B. costatus*. There are good specimens of *Bucanopsis exilis* (de Kon.); *Waagenella férussaci* (d'Orb.), *W. rectistriatus* Weir, and *Euphemus* sp. There are over 700 other specimens of gastropoda including *Euomphalus pentangulatus* (126), *Platyceras* spp., 14 Capulids, 64 *Straparollus fallax*, 44 *S. dionysii*, 223 *Pleurotomaria carinata* and *Pleurotomaria* sp., some with colour bands still preserved, 59 Murchisonidae and Loxonematidae, 250 *Naticopsis* spp., and 30 good specimens of *Metoptoma* sp.

In many specimens the protoconch is preserved and in some the aperture is practically complete.

Cephalopoda

There are over 100 goniatites preserved solid in Limestone in the collection, but none of them is accurately localized. They include *Goniatites crenistria*, *G. involutus*, *G. maximus*, *Beyrichoceras micronotum* (group), *B. vesiculiferum* (group), *B. obtusum* (group). There is one beautiful specimen of *Beyrichoceras castletonense*, and many good *B.* cf. *phillipsi*. There are many good specimens of *Nomismoceras* spp.; *Dimorphoceras* is probably represented though none is septate; and there is a single specimen with acute venter, probably a *Sagittoceras*. Orthocerates are plentiful including a fragment of a large *Actinoceras* and a well-preserved *Cyrtoceras*. Among the coiled forms are four specimens of *Discitoceras* sp., several *Subclymenia evoluta* Phillips, and many "Nautilus"-like forms.

Lamellibranchia

Only thirty-four specimens of common knoll forms.

BRACHIOPODA

This phylum is represented by an enormous number of specimens. Among the Orthotetinae, *Streptorhynchus senilis* (Phillips) is the commonest; but there are also examples of

Schellwienella ornata Demanet, as well as a number of specimens which need grinding before they can be determined.

There are over 2,000 Orthids in the collection, including *Rhipidomella michelini* (L'Eveille) with many valves showing internal structure; *Schizophoria resupinata* (Martin) and many of Demanet's varieties; *Schizophoria* sp. nov.; *Aulacophoria keyserlingiana* (de Kon.), and an ? *Aulacophoria* which is probably new.

There are more than 3,000 Rhynchonellids, showing great variation, and including the common knoll facies forms *Pugnax acuminatus*, *P. pugnus*, *P. mesoloba ;* "*Rhychonella*" *angulata* Linn.

A drawer full of over 450 Dielasmas show variation over a wide range.

The Spirifers, both smooth and costate forms, are probably second to the Rhychonellids in abundance and show a bewildering intergradation between species, a small *Martinia* sp. being perhaps the most common fossil in the collection.

There is a particularly good collection of *Leptaena* spp., including sixty good specimens of *Leptaena distorta* Sowerby, with apparently every gradation into *Leptaena sinuata* de Koninck as regards external form.

The Producti form another well-represented suite. The pustulose forms include *Pustula subelegans* I. Thomas, over 200 good specimens; *P.* cf. *ovalis* (Phillips); *P. elegans* (M'Coy); *P. venusta* I. Thomas; *P. pustulosa* (Phillips); single specimens of *P. tenuipustulosa* I. Thomas, *P.* cf. *rugata* (Phillips); three specimens of a form which may be new; *Overtonia fimbriata* (J. de C. Sow.); *Plicatifera mesoloba* (Phillips); *P. plicatilis* (J. de C. Sow.). In this group as with others there is a wide range of variation in form and size of the specimens, with a good number of well-preserved young forms. The groups *Productus longispinus* and *P. semireticulatus* are abundant. There are a few Buxtonias and several Avonias.

COELENTERATA

Corals are scarce.

PLANTAE

No Calcareous algae or other plants.

The collection gives a good idea of the relative abundance of the various brachiopods in the Reef Knoll fauna, and must represent the result of years of careful collecting by Tiddeman, who paid attention to even the smallest forms: for instance, there are specimens of *Schizophoria* ranging down to about ⅛ in. in length. Furthermore, there are a number of specimens which show the effects of deformation and injury during life, and these have been separated from the rest and placed by themselves.

The collection has been catalogued in such a way that specimens are quickly found, the catalogue showing at a glance the quantity of material of a species, or group of species contained in the collection. Since large numbers of certain species are represented it is thought that the collection might prove of value to those interested in the statistical treatment of variation, particularly as specimens of extremely young individuals as well as mature and old age forms are often abundant.

In conclusion I wish to acknowledge my gratitude to the Craven Naturalists' Society, Mr. T. H. Holmes, Trustee of the Mechanics' Institute, and Mr. David Etty, Curator of the Skipton Museum, for permission to borrow specimens and to examine the collection ; to Dr. A. Raistrick, Honorary Curator, at whose suggestion the work was undertaken ; to Mr. Midgley, Head of the Science and Art School in Skipton for kindly providing me with a room in which to work ; and to Dr. Alan Wood of the Imperial College of Science who helped with the preliminary inspection of the collection.

The Malignite of Poohbah Lake, Ontario

S. J. Shand, Columbia University, New York

IN an article on " Limestone and the Origin of Feldspathoidal Rocks ", which appeared in the *Geological Magazine* ten years ago, I referred to the malignite of Poohbah Lake, Western Ontario, and was so bold as to predict that " further work at Poohbah Lake . . . will eventually furnish evidence of the presence of limestone in contact with the alkaline eruptives ".[1] In August, 1939, I found myself at last in a position to visit the locality and see how far my prediction could be verified.

Poohbah Lake is one of the hundreds of glacial lakes that are hidden away in the Quetico Forest, in the Rainy River district of Western Ontario ; it is in lat. 48° 23′, long. 91° 41′, and is shown on sheet 52B (Quetico) of the topographic map of Ontario on the scale of 4 miles to 1 inch. The Rainy River district was surveyed geologically and topographically by a field party of the Geological Survey of Canada, under the direction of A. C. Lawson, about the year 1890.[2] The country is heavily forested and all that is not under forest is drowned beneath innumerable lakes and swamps.

Useful exposures are almost entirely confined to the narrow zone of wave action around the margin of the lake and its numerous islands. During a stay of four days I collected varieties of malignite from the rocky ledges at various points around Poohbah Lake, and made a traverse to Wink Lake, but it seemed unprofitable to attempt more than this. The only rocks to be seen, apart from malignite and the abundant granite erratics, are occasional ridges of mica-schist and staurolite-mica-schist. If any limestone is there it is drowned beneath lake or swamp. In the absence of adequate exposures it is clear that one may neither assert nor deny the presence of limestone in that region.

It was my intention, in going to Poohbah Lake, not merely to look for the predicted limestone but to make some further contribution to the mineralogy and petrography of malignite ; but since my return I have learned from Professor Grout, of the University of Minnesota, that one of his students is already engaged in such a study. For this reason I shall confine myself here to a few observations of a general character.

My specimens of malignite include both porphyritic and non-porphyritic facies and all three of the mineralogical varieties that Lawson distinguished. Through the kindness of Professor Howel Williams I was able to study the original specimens and thin sections upon which Lawson's description was based, and I find them to be duplicated in every essential respect by my own specimens, although none of mine is so rich in garnet as Lawson's no. 506. Only two of my specimens are appreciably different from Lawson's ; one is a coarse-grained syenite from Wink Lake, and the other a variety of the nepheline-pyroxene-malignite which is almost free from felspar and thus virtually an ijolite. As regards the distribution of the varieties in the field, I find that amphibole is not confined to the northern border—the supposed roof of the intrusion—or garnet to the southern border—the supposed floor. I collected garnet-bearing varieties in the north and east as well as in the south-west ; and amphibole-bearing rocks at several points on the west and south-west and also at Wink Lake. The nepheline-malignite occurs, as Lawson indicated, at various points along the west and south shores of the lake. On the whole, I have found nepheline chiefly in the more fine-grained, non-porphyritic facies and garnet and amphibole in the coarse-grained and porphyritic rocks. The distribution of these textural facies seems to be a random one.

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[1] *Geol. Mag.*, lxvii, 1930, 423.

[2] *Ann. Rep. Geol. Surv. Canada*, vol. v, part G, 1890–1.

The following mineral associations occur among Lawson's specimens and mine :—

A. *Without nepheline ; texture porphyritic or coarse-grained*

(1) diopside-biotite
(2) diopside-amphibole
(3) diopside-amphibole-biotite
(4) diopside-garnet-biotite
(5) garnet-biotite

B. *With nepheline ; texture even, medium-grained*

(6) diopside alone
(7) diopside-biotite

Garnet was never observed in association with amphibole ; on the other hand it is always accompanied by biotite. The proportions of garnet and diopside vary inversely, and the textural relations between the two species indicate that the garnet is a product of transformation of diopside. The usual mode of occurrence is that tiny, irregularly shaped grains and patches of garnet lie within hypidiomorphic prisms of diopside. Less frequently one sees grains of diopside enclosed in garnet ; and when no diopside is present at all then allotriomorphic grains of garnet are intergrown with biotite and sphene. Since the garnet is always allotriomorphic and always forms very small grains even when it is most abundant, whereas diopside forms stout hypidiomorphic prisms, it seems certain that it is the garnet and not the diopside that is the product of transformation. The formation of melanite from a diopsidic pyroxene was described by R. A. Daly [1] in rocks of Kruger Mountain, British Columbia, and was attributed by him to crush-metamorphism. The garnet in the Poohbah rocks is a light brown andradite rather than melanite; its physical properties are somewhat variable (or at least difficult to determine on account of its minute intergrowth with sphene), but the density is about 3·75 and the refractive index greater than 1·83.

The proportions of the various minerals show a wide range. Lawson furnished only one computed mode—that of the nepheline-pyroxene-malignite—as follows:—

orthoclase	20·9
nepheline	19·6
aegirine-augite (slightly sodic diopside)	48·2
apatite	5·8
biotite	2·0
sphene	1·0

In order to separate some grains of garnet for study I crushed a piece of my variety 4 and fractionated the powder with heavy liquids. I found it impossible to effect a good separation of the minerals, owing to the small size of many of the grains and their mutual intergrowth, but the following proportions were indicated:—

orthoclase	39
diopside (including a little biotite and apatite)	54
andradite	4
sphene	3

One of Lawson's specimens is rich in garnet; I estimate that it contains nearly 30 per cent of intergrown andradite and sphene. The most melanic rock in my collection holds about 60 per cent of diopside, 30 per cent of nepheline, and only accessory proportions of orthoclase, apatite, and sphene; the most leucocratic—the syenite of Wink Lake—holds 75 per cent of alkali-felspar along with diopside, sphene, and iron-ore.

It is clear that the name malignite is too comprehensive for systematic use, for it covers rocks that range from syenite through foyaite to ijolite. The melanic syenites are adequately covered by L. V. Pirsson's name shonkinite, which has priority over malignite by one year. The definition given by Pirsson reads as follows: "Shonkinite is a granular plutonic rock consisting of essential augite and orthoclase . . . accessory nepheline, sodalite, etc., may be present in small quantities." In spite of Rosenbusch's extension of this name to rocks containing quite large proportions of nepheline, it is proper to hold fast to Pirsson's definition. The name malignite should then be restricted to Lawson's nepheline-pyroxene-malignite and other examples of melanic foyaite.

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[1] *Geol. Survey Canada, Mem.* 38, 1912, 449.

Rocks of the character of shonkinite and malignite, which are rich at once in potash felspar and in lime silicates, are most uncommon. The best examples known to me are the following:—

Shonkinite, Palabora, Transvaal. (S.J.S.)
Borolanite and ledmorite, Loch Borolan, Scotland. (S.J.S.)
Sviatoynossite, Transbaikalia. (Eskola.)
Shonkinite, Predazzo. (Ippen.)
Shonkinite, Highwood Mts., Montana. (Pirsson.)
Shonkinite (theralite), Crazy Mts., Montana. (Wolff.)
Malignite, Kruger Mt., B.C. (Daly.)
Shonkinite, Crown Hill mine, Ottawa. (Osann.)
Shonkinite (marosite), Celebes. (Iddings.)
Shonkinite, Kaindy River, Turkestan. (Nikolaiev.)

I refrain from quoting chemical analyses in full, but each of these rocks contains more than 4 per cent of K_2O contained in potash felspar, together with 7 to 16 per cent of CaO which is mainly contained in diopside, garnet, and other non-aluminous silicates, including unusually large quantites of sphene and apatite. There is a striking sympathetic variation of potash and lime, as the following figures show:—

Locality.	*K_2O.*	*CaO.*
Loch Borolan .	4·09	8·32
Sviatoy Noss .	4·16	7·34
Crazy Mts. .	4·49	9·57
Poohbah Lake .	4·57	10·81
Shonkin Sag .	4·60	11·56
Kaindy River .	4·60	12·25
Celebes . .	5·06	11·56
Predazzo . .	5·12	12·39
Poohbah Lake .	5·25	14·36
Palabora . .	5·60	16·70
Shonkin Sag .	5·61	9·35
Ottawa . .	5·62	10·00
Kaindy River .	6·62	10·66
Kruger Mtn. .	6·86	7·99
Loch Borolan .	8·05	10·29

The decrease in lime in the last five rocks is easily explained; the Palabora shonkinite with 5·6 per cent of potash consists almost entirely of microcline and diopside, so any further increase in the proportion of potash felspar must take place at the expense of the lime minerals. Observe how nicely the two rocks from Poohbah Lake fall into place in the series.

Now the rocks of Palabora, Loch Borolan, Sviatoy Noss, Predazzo, and Kaindy River occur in actual or virtual contact with limestone ; the rocks of Shonkin Sag and the Crazy Mts. in Montana overlie massive Palaeozoic limestones (the Madison limestone alone is 1,000 to 1,800 feet thick) ; the Celebes rock occurs in a region of thick Tertiary limestone ; the Kruger Mt. rock is intrusive in series of crystalline schists which includes limestone members ; and the Ottawa occurrence is associated with calcsilicate rocks and apatite-pyroxenite. In view of these facts I am not discouraged by my failure to locate any body of limestone at Poohbah Lake ; I still stand by my prediction, although it may be longer than I had anticipated before it can be verified.

Wartime Lessons in Erosion

By E. B. Bailey, Director of the Geological Survey of Great Britain

(PLATE III)

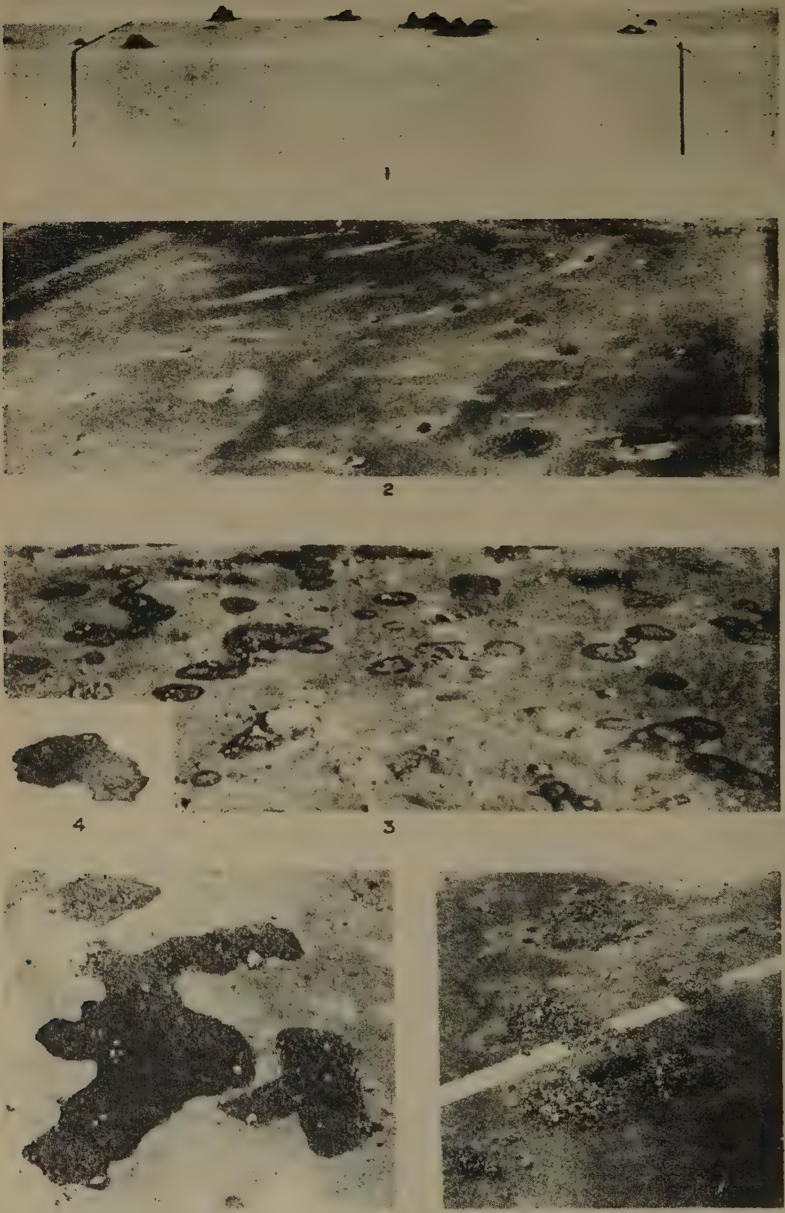
During September, 1940, there were many falls of earth and other things upon the roofs of London. An example that I had excellent opportunities of studying consisted of loam, and gravelly loam, distributed in discrete patches over an extensive area. The material must have fallen from a considerable height, for everywhere it moulded itself with flat base to suit its foundation; and, whether forming mere pellets or splashes a few feet in diameter, it developed a surprisingly uniform summit level of little more than 1 inch in height. On breaking the loam across, one always found a system of close, roughly horizontal cracks, a type of rude joint cleavage. This structure persisted despite frequent wettings and dryings, even though when wet the loam became quite sodden.

Most of the material fell on impermeable tar felt, a little on impermeable sheet lead, and a moderate proportion on permeable Portland Oolite. For a fortnight of alternating breeze and calm, wet and fine, with a considerable share of sunshine and no night frost, the loam weathered progressively, until finally it was gathered to its rest by an impatient broom. During this time many of the patches had completely disintegrated to yield debris, scattered several feet by wind and rain. More of them, however, still retained their individuality, well illustrated in the accompanying photographs kindly taken by Mr. John Rhodes.

The nature of the foundation exercised a considerable influence upon the subsequent erosion of the fallen material. It mattered a good deal whether the foundation were impermeable or permeable, and whether from its shape it hindered or favoured a rapid run off. Let us first consider material that fell on tar felt or lead. Some came to rest on slight depressions of the main roof, where pools formed during showers and lingered after: they proved particularly prone to destruction. Others standing on slight rises of the same area suffered somewhat less. Others again mounted on narrow terraces or parapets, with quick run off, were definitely more permanent. Finally we may turn to those that rested on permeable coping stones of parapets (Pl. III, fig. 1): they wasted scarcely at all during the fortnight. They showed, however, the same type of effects as are described below, only in greatly reduced measure. As soon as rain ceased it was impossible to recognize any marginal seepage keeping the surrounding stone moist. In this they differed markedly from pellets mounted on tar felt, since these latter supplied miniature springs for several hours after they had ceased to receive water from the clouds (Pl. III, figs. 3, 4, 6).

The weathering of the pellets was superficial and marginal. Close examination revealed a sandy or gravelly skin, extending over the greater part of the surface, but assuming much bigger proportions towards the edges. Springs thrown out near these edges led to removal of the finer material and concomitant back-cutting of the nucleus. Pl. III, fig. 5 shows a patch that originally consisted of gravelly loam. By the time the photograph was taken, it had mostly disintegrated to gravel, though still retaining a central relic with miniature undercut margin. Much loam matrix had been washed away to a distance, but it is clear from the picture that a little had been dropped just outside the residual gravel. While less marked in many cases, a similar spatial sequence from central relic, through intermediate coarse concentrate to fine outer deposit furnished the type plan of the whole eroded assemblage. The coarse concentrate varied in nature from outwash apron to untravelled settled residue. The loamy matrix of gravelly loam disappeared more quickly (Pl. III, figs. 5, 6) than the loam of adjacent non-gravelly pellets. This was due to the fact that stones once exposed served as tributary catchment areas directing water upon intervening matrix.

The gravel of Pl. III, fig. 5, contained at its base some freshly deposited silt, as became obvious when under dry conditions the whole was eventually dealt with by the broom: the loam nucleus was swept clean away, but the silt at the base of, and fringing, the gravel left a thin film soldered to the foundation. The same phenomenon was illustrated in a hundred other instances, not necessarily gravelly, so that for long after the day of brushing the roof was marked by fairy rings, or atoll shapes, of clinging silt. Moreover, before they had suffered from the broom, the central cores of the patches could always in dry weather be lifted more or less bodily up, and their smooth fall-bases examined. In fact drying led to a crevasse of separation between unworked core, which contracted as a unit, and reworked edge, welded to its foundation. These characteristics were universal. They were shown, for instance, by pellets that had stood repeatedly for hours in shallow pools, and by others mounted on quick drying permeable coping stones.



A FORTNIGHT'S EROSION.

It was often difficult or impossible to distinguish satisfactorily effects due to outward flow of water that alighted on the pellets from others caused by currents of passing sheet floods or by ripples of surrounding pools. One could, however, study the effect of wind upon the activities of streams descending from the spring line in periods of calm rainfall, when a puff from an observer would set silt flowing where previously all had been clear. On the other hand the wind-directed tails of rainwash illustrated in Pl.III, fig. 2 were certainly in large measure carried by external rainfall.

DESCRIPTION OF PLATE III

Fig. 1.—Pellets of loam about 1 in. high on a parapet coping of permeable Portland Oolite.

Figs. 2–6.—On impermeable tar felt roof.

Fig. 2.—The main pellet in foreground is 6 inches long. Many pellets show rainwash trails.

Fig. 3.—Patches, 1–2 inches long, show seepage some hours after rain.

Fig. 4.—Patch, 8 inches long, with persistent seepage.

Fig. 5.—Residual gravel surrounding relic of gravelly loam, the whole 2 feet long. Outwash silt also visible.

Fig. 6.—Gravel residuum of original gravelly loam, 2 ft. 6 in. long. Note see page.

Microscopic Colloform Structures in "Mud Balls" at Waiotapu, New Zealand

By J. A. Bartrum, Auckland University College

(PLATE IV)

A RECENT paper in this journal by K. P. Oakley (1940) has drawn attention to certain structures in Recent rhyolitic ashes of Malaya, and contraverts the earlier view that these structures represent sponge spicules. Oakley suggests tentatively that most of them are the casts of minute spherical and tubular hollows in the material of the ashes. It may be of interest, therefore, to describe comparable material from New Zealand which appears to support this suggestion.

In January of 1937 Dr. L. I. Grange, whose Geological Survey *Bulletin* (1937) excellently describes the geology of the region concerned, kindly guided other visitors and the writer of this paper around Waiotapu, one of the hot spring areas of the Rotorua-Taupo region, and showed them the excellent mud balls, or pisolites as he prefers to call them, that are illustrated in Pl. IV, fig. 1. They occur in great number in a limited area intermixed with sinterous muds from adjoining hot springs; similar bodies are described by Grange (1937) from elsewhere in the region in water-bedded sands as well as under other conditions of occurrence. In private communications Dr. Grange states that he is inclined to regard these mud balls from Waiotapu as belonging to the type of pisolite to which Berry (1928) has given the name of chalazoidite, believing that they accreted in the higher atmosphere from the dust of pumice eruptions. The present writer, however, believes that a strong case can be presented in favour of regarding the Waiotapu examples as accretions cemented by mud in the surging waters of hot springs and comparable, therefore, with the large calcareous pisolites of the Carlsbad hot springs. Their size varies from a little under ½ inch to 1 inch or more in diameter and at times they are so closely appressed as almost to exclude surrounding matrix (see Pl. IV, fig. 1). They are fragile, readily being pulverized by the fingers, and, if fallen from the higher atmosphere it is difficult to conceive how they escaped being smashed to fragments by impingement one on another upon reaching the ground. Their high degree of concentration on the margins of the springs also is suggestive of origin in these latter. Around the muds in which they occur there are Pleistocene lake terraces built largely of fine pumiceous débris.

The writer cut diametral thin sections from three of these mud balls, and these sections demonstrate that the method of accretion varied. One thin section shows no noticeable variation of texture throughout; another 20 mm. in diameter possesses an outer envelope of fine mud about 1 mm. in thickness within which is decidedly coarser material cemented by mud; the third has a fairly coarse core 3 mm. across, then a ½ mm. shell of mud which gives place to a coarser layer 1 mm. in thickness, which is followed by a zone of mud ½ mm. in depth. Thence to the periphery there is the relatively coarse débris that characterizes the other pisolites. This has a cementing medium of impalpable mud in which are enclosed small shreds of glass, seldom over 0·1 mm. in length, scattered broken crystals of ? plagioclase usually not exceeding 0·05 mm. in diameter, numerous tiny tubular masses that resemble altered pumice, and an abundance of the microscopic colloform [1] bodies which are the main subject of this paper. It is to be noted that these latter typically show minute concentric ring systems and that occasionally these are to be seen plastered in considerable numbers on the parallel tubules of what appear to represent tiny fragments of pumice.

A fourth thin section was prepared from the material interstitial between the balls; this is decidedly coarser in texture than that of these latter and contains numerous fairly large shreds of volcanic glass, little fragments of pumice, and colloform structures which are very much larger, but less numerous, than those of the balls themselves and do not appear to have any genetic relation to the other constituents (see Pl. IV, fig. 2). Much of the glass is a product of the explosive disruption of vesicles, as is indicated by shapes such as that of Text-fig. 1, No. 14, and Y or stirrup-shaped forms.

The material of the colloform structures appears to be opal, for it has a refractive index decidedly less than that of Canada balsam; usually it is a light brown colour and crossed by closely-crowded parallel rings of deeper brown colour reminiscent of the annular rings of the wood of plants, or by systems of minute concentric circles. Tubular forms may have their ends closed or open and may be either straight or curved; sometimes they are irregular (Text-fig. 1, Nos. 1–3, 12). The rings may characterize only a portion of the tube, especially if it is clear and glassy (Text-fig. 1, Nos. 3 and 12), and in many of such tubes they are wholly absent. In addition to the rings a number of the tubes show minute series of concentric circles which give the appearance of buds, or these latter may occur without the rings (Text-fig. 1, Nos. 1 and 11).

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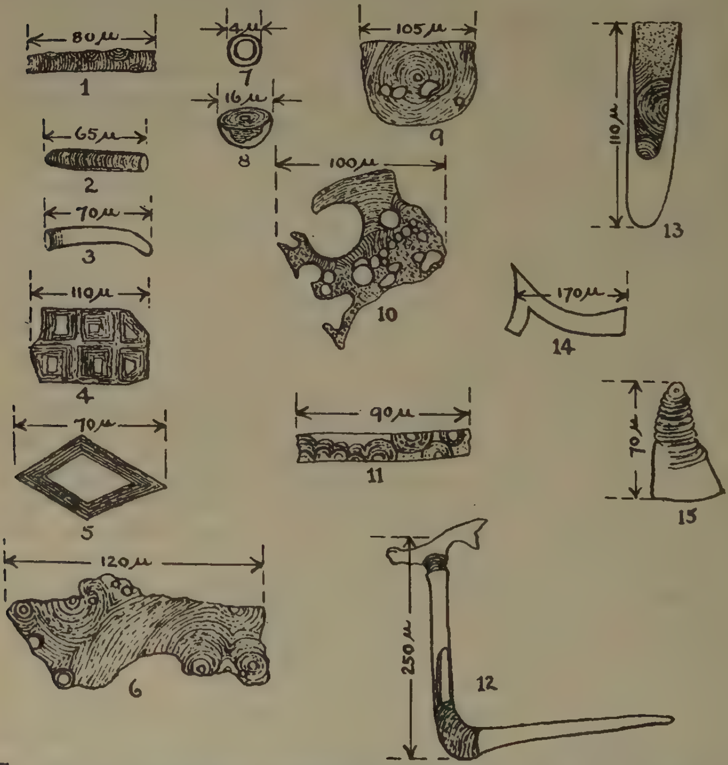
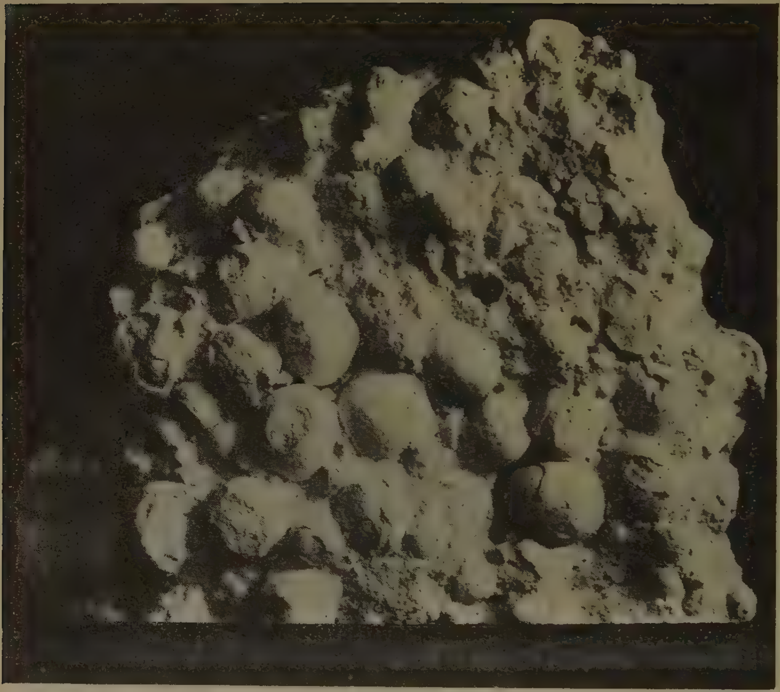
[1] This term was introduced by Rogers (1917) for "the rounded, more or less spherical, forms assumed by colloidal and metacolloidal substances in open spaces".

By far the most abundant of the colloform structures are simple rings such as No. 7 of Text-fig. 1, which are present in extraordinary number. At first it was suspected that these represented filamentous diatoms; one or two valves of these latter were noted, however, and in each instance bore the usual minute radial markings. It appears probable, therefore, that these simple rings are merely disruption products of the annular tubes already described. Irregular, much larger bodies marked by systems of concentric circles are also ubiquitous, some of them even simpler in design that Text-fig. 1, No. 9, others



Text-fig. 1.—Approximate sketches (except No. 14) of varied colloform structures in the mud balls of Pl. IV, Fig. 1. No. 14 is a shred of volcanic glass from the matrix between the balls.



more complex as in Nos. 6 and 10 of this text-figure. Almost invariably a strongly marked ring or double-ring occurs near the centre of each system of circles.

In view of the possibility that some of these structures represent silifications of algae, the thin sections were sent early in 1937 to the late Professor W. A. Setchell, of the University of California, Berkeley, who reported privately that he could not confirm the presence of algae, but was inclined to believe that some of the structures represented silicifications of macerated coniferous wood. Indeed a solitary example of what well may represent such wood is figured in Text-fig. 1, No. 4.

Laminated structures such as No. 5 of Text-fig. 1 are not infrequent and appear definitely to be the partial or complete fillings of cavities, so that tubular forms likewise may be the casts of the minute tubes of pumice. In this connection No. 13 of Text-fig. 1, which portrays a unique example, may be taken to exemplify how, in the filling of a cavity, series of concentric circles may develop. It is impossible to explain wholly as cavity fillings most of the larger structures illustrated, especially that of Pl. IV, fig. 2, with its laminated bands of brown glass which enclose or even pass through the series of concentric rings shown. It may be suggested that such masses have developed largely by superficial silicification, imposed perhaps upon some cavity filling, for several fragments of what appears to have been pumice with parallel tubules have grown concentric rings far beyond the confines of individual tubes. The alteration of the volcanic glass concerned and the incidence of silicification at Waiotapu have probably been facilitated by acid waters; Grange (1937) notes that most of the springs of this locality are acid and contain chlorides.

The writer regards the suggestion of origin of these opaline structures that he has set forth as tentative and will welcome more adequate explanation of the phenomena evidenced.

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EXPLANATION OF PLATE IV

Fig. 1.—Mud balls from Waiotapu Hot Springs, New Zealand, thermal region. The largest is an inch in diameter. E. J. Searle, collector

Fig. 2.—Opaline colloform growths in matrix of mud balls of Fig. 1. × 270.

A Problem in Polyzoan Nomenclature.

By R. M. Brydone

IN 1838 Johnston in the first edition of his *History of British Zoophytes* instituted a genus *Lepralia* (the middle *a* should from its derivation be short) with seven type species—*Cellepora hyalina* Linn., *Berenicea nitida* Flem., *Berenicea immersa* Flem., *Cellepora coccinea* Abild., *Eschara ciliata* Pall., *Discopora trispinosa* Johnst., and *Lepralia variolosa* nov. The genus has had a very chequered career, as well as very heavy use.

Gray, in 1848, transferred *Cellepora hyalina* to a new genus *Celleporella*, and *Berenicea immersa* and *Lepralia variolosa* to a new genus *Escharella*, and *Cellepora coccinea* to a new genus *Escharina*, leaving only *Berenicea nitida*, *Eschara ciliata*, and *Discopora trispinosa* as rival types of *Lepralia*.

In 1873 Smitt removed *Berenicea nitida* to his new genus *Membraniporella* as its type; and Hincks (1877, p. 526) removed *Eschara ciliata* to a new genus *Microporella*, thus completing the transformation of *Lepralia* into a genus with only one type species, *Discopora trispinosa* Johnston.

Hincks (1879, p. 160) founded a new genus *Smittia*, with *Lepralia landsborovii* Johnston the first species, and *Discopora trispinosa* the sixth species which he assigned to it. It would seem clear that *Smittia* was synonymous with *Lepralia* as that genus had stood since 1877, i.e. a genus of which *Discopora trispinosa* was the sole type species, though Hincks had apparently failed to appreciate this. (The name *Smittia* was shortly afterwards discovered to have been preoccupied.)

In 1903 Norman discussed the history of the genus *Lepralia* (1903, p. 99) and after saying that *Lepralia* was a name so old and familiar that it could hardly be " dropped as a synonym " pointed out that no one had selected a type for the genus and suggested that *Berenicea nitida*, the second species listed by Johnston, be regarded as the type of the genus, passing over the first of Johnston's species, *Cellepora hyalina*, because it had (at an earlier page in the same paper) been transferred to another genus. This objection would, by 1903, apply with at least equal force to each of Johnston's list of species. He also set up (at p. 120) *Smittina* as a new name, what for is not precisely stated but apparently for the species Hincks attributed to *Smittia* in 1879 (including *Discopora trispinosa*), and he expressly made *Lepralia landsborovii* the type species of *Smittina*.

Norman's action is apparently technically within the Rules, notwithstanding that *Lepralia* had been reduced to a one-type genus some twenty-five years previously; but I cannot think that the framers of the Rules realized that such action would be covered, or that if it was, they would not have put some restriction on the generality of the power of selection given by them.

Lang, in 1917 (quoted as 1921 in Bassler, 1934), accepted (p. 171) *Berenicea nitida* as the genotype of *Lepralia*.

In 1920 Canu and Bassler, in their monumental *North American Early Tertiary Bryozoa*, took the point that Norman's lectotypic action was not the obligation which he claimed it to be, and described his particular selection of *Berenicea nitida* to be the lectotype of *Lepralia* as unfortunate, since that species was already the genotype of *Membraniporella*. They ignore Norman's *Lepralia nitida* and treat *Berenicea nitida* as the genotype of *Membraniporella*, rather regrettably speaking of it as *Lepralia nitida* Johnston and *Membraniporella nitida* Johnston, when the author of the species is Fleming. On the ground that *Lepralia landsborovii*, the first species among those described as *Smittiae* by Hincks in 1880, was not a very satisfactory species, they proclaimed *Lepralia reticulata* Macgillivray, the second of these species, as the genotype of *Smittina*.

In 1935 Bassler, in W. Quenstedt's *Fossilium Catalogus*, recorded *Lepralia nitida* (which he still assigned to Johnston) as the genotype of *Membraniporella* and also of *Lepralia*, and recognized *Lepralia landsborovii* as the genotype of *Smittia* and also of *Smittina*, and stated that *Lepralia* was used (but he did not say by whom or give any reference for this alleged use) " for some unplaced species of *Hipporininae* " (presumably a misprint for Hippoporinae).

The conclusion left in my mind is that the so-to-speak negative selection by 1877 of *Discopora trispinosa* as sole type of *Lepralia* had the effect of shutting out by 1903 the application of the rule authorizing lectotypism and that therefore *Discopora trispinosa* is now the genotype of *Lepralia*; *Smittia* and therefore necessarily *Smittina* are synonyms of *Lepralia*; and *Berenicea nitida* is still the genotype of *Membraniporella* and of no other genus; Norman's selection of it as the lectotype of *Lepralia* thirty years after it had been made the type of *Membraniporella* was not valid and effective. If it both had been valid and had become effective it would not have been practicable until *Lepralia* had been re-defined in terms of *Berenicea nitida*, which seems to indicate a weakness in the Rules of Nomenclature and a burden not unreasonable to be laid on practitioners of lectotypism.

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CORRESPONDENCE

SOME PROBLEMS OF GEOMORPHOLOGY AND CONTINENTAL RELATIONSHIP IN BRITISH GUIANA

SIR,—I am unable to accept Dr. Junner's strictures on the accuracy of my remarks about the geology of West Africa published in the January-February number of the *Geological Magazine*, for the following reasons :—

1. *Kawere Group.*—It is clear that Dr. Junner restricts this name to the basal sediments of the Tarkwaian system. In the paper by W. J. Hughes and myself (1) based on field work in 1925–7, the term " Kawere " group or facies was referred specifically to the volcanic series of lavas, pyroclastic and perhaps spilitic rocks which were named after the Kawere valley where they occur, and which intervene between the upper normal sedimentation of the Birrimian series, and the basal beds and normal sedimentation of the Tarkwaian series. Indeed, the final proof of the latters' unconformity with the Birrimians was provided by these writers (*pace* the late Sir A. E. Kitson) (1, discussion, p. 178), although he did not altogether approve of their use of the name Kawere. However, I do not think we should have used this name, if at that time the Gold Coast Geological Survey had adopted it exclusively for the basal Tarkwaian sediments. Even so, it does not appear that

Dr. Junner's sweeping statement " the Kawere group does not contain any volcanic agglomerates " was entirely supported by Whitelaw (2) who refers to volcanic activity accompanying the Kawere group.

Dr. Junner's later work (3) has come into my hands since my Guiana paper appeared, and I can detect in the former no material discrepancy between his account of the Gold Coast succession and that outlined by Bishopp and Hughes (1), except on this point of nomenclature. In our 1930 paper it was expressly stated (author's reply to discussion) that *Tarkwaian rocks were not included among the volcanic rocks of our " Kawere facies "*, which Dr. Junner properly assigns to the Upper Birrimian. Hence the comparison which I have made with the sequence of similar types in British Guiana.

2. *Trend Lines.*—According to Dr. Junner's map (3, plate 2), the trend lines appear to have, in the average, more northing than north-east. Thirty-three degrees would be a better approximation than either N.E. or N.N.E. While in Sierra Leone there is a change of trend to north and north-west, it does not appear that a north-easterly strike can be entirely excluded.

3. *Voltaian Escarpment.*—(*a*) Nowhere have I suggested that the present scarp-line is to be identified with a fault. I do suggest, however, that it may have retreated under erosion back from an original coastal fracture (cf. du Toit, (4), pp. 256–7).

(*b*) Distances : Dr. Junner, avoiding mention of the relationship of the scarp with coastal trends, says it is 50–150 miles (80–240 km.) from the coast. Kitson (5) gives it as 40–220 miles (64–352 km.).

A glance at the map (3) shows the scarp-line running northwesterly—may one suggest west-north-westerly—at about 303°, almost at right angles to the older tectonic lines. But the coastline has two significant directions : one nearly parallel to the scarp, and the other approaching it at a high angle. In the first case the distance normal to the scarp-line between, say, near Mpraeso and the coast at Cape Three Points is about 254 km., increasing to about 312 km. measured from the inflexion of the scarp-line near Wenchi to the coast west of Half Assini.

Thus, the meaning of my expression " the escarpment set back some 300 km. from the coast " seems clear enough in the light of du Toit's criteria, irrespective of the scarp's closer relation to a different coastal trend south-east of Koforidua.

4. *Gorceixite.*—I must express my regret to Dr. Junner for the *lapsus calami* in my reference to his discovery, which would

no doubt have been corrected, if access to the literature had not been interrupted. It is of considerable interest to note from the Report of the Imperial Institute for 1940, that a similar mineral has recently been discovered in British Guiana by the Geological Survey.

5. *Coast-line and Coastal Faulting.*—Dr. Junner's letter does not mention his own references to coastal faulting in the work he has cited (3, p. 34), while Kitson (5) makes emphatic statements as to the considerable fracturing and downfaulting of blocks at the coastal margin. If these views are inaccurate or misleading, is Dr. Junner now able to state definitely that coastal faulting is not appreciably developed?

For comparison purposes age-determinations by the helium and radioactive methods for the principal rock-types in West Africa and Guiana would be welcome; while in the latter country a more detailed study of the flat-lying Kaieteurian beds with their large associated intrusive gabbros and dolerites has long been desirable. Dr. Junner's warning as regards correlation of unfossiliferous sediments and igneous rocks over great distances seems out of place here, since we are trying to test an hypothesis that at one time the rocks of West Africa and Guiana were, after all, not very far apart. The question is, if joined, how well would they correlate; the tentative answer at present seems to be, not at all badly.

D. W. Bishopp.

14 Hume Street,
Dublin.
29th March, 1941.

(1) A contribution to the geology of the manganese ore-deposits in the Gold Coast Colony and in Ashanti. (With discussion and author's reply.) D. W. Bishopp and W. J. Hughes, *Trans. Inst. Mining Met.*, 1929–1930.
(2) *Gold Coast Geological Survey, Memoir No. 1*, 1929.
(3) *Gold Coast Geological Survey, Bulletin No. 11*, 1940.
(4) *Our Wandering Continents*, Oliver and Boyd, 1937.
(5) *Gold Coast Geological Survey, Bulletin No. 1*, 1925.

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The Igneous Rocks of the Stanner-Hanter District, Radnorshire

By Norman Holgate and K. A. Knight Hallowes

I. Introduction (K. K. H. & N. H.)

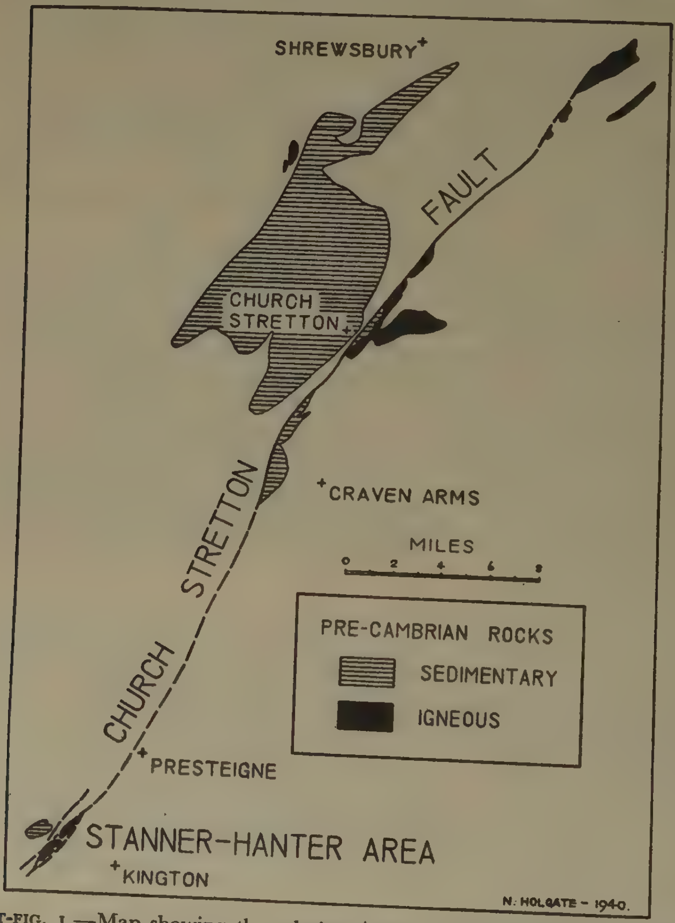
The igneous rocks of the Stanner-Hanter district are included within the Geological Survey 1-inch map, sheet 56 S.E., (Old Series), and form three hog-backed hills, Stanner Rocks, Worsell Wood, and Hanter Hill, which are prominent features in the country between New Radnor and Kington, close to the Welsh border. This line of hills trends from south-west to north-east, though the separate ridges are arranged *en échelon*. Stanner Rocks (1,081 feet), is separated from Worsell Wood (about 940 feet), by the alluvial plain of the Gilwern Brook, while there is a low col between Worsell Wood and Hanter Hill (1,361 feet).

In May, 1935, one of the authors (K. K. H.) commenced work on Stanner and, in the following year, the other author (N. H.) began an investigation of the same hill, and of Worsell and Hanter which extend from it to the south-west, for the mapping of which he is entirely responsible, Stanner Rocks being joint work. The authors had come, independently, to the conclusion that the Stanner-Hanter massif is not intrusive into the surrounding Silurian flagstones, as Murchison and others believed it to be, but that it is a faulted inlier of Precambrian rocks. Callaway, as long ago as 1879, had hinted that this might be so.

History of Previous Work (K. K. H. & N. H.)

Murchison (1838 and 1867) considered the Stanner-Hanter ridge to be composed of " hypersthene trap ". He regarded it as intrusive into the surrounding Ludlow sediments.

Callaway (1879) believed that a ridge of Precambrian rocks continues from Lilleshall and the Wrekin, through Caer Caradoc, Stanner, Worsell, and Hanter, a distance of nearly 50 miles. In a later paper (1900) he drew attention to the fact that the Church Stretton Fault runs south-west to Old Radnor, and that at Church Stretton the Longmyndian grits occur on the west side of it, with the Uriconian rocks of Caer Caradoc on its eastern margin. In the Old Radnor area Precambrian grits were discovered by him on the west side of the same fault and, on the map attached to his paper, he wrote: "The Uriconian age of part of the masses west of Kington [i.e. the hills of



Text-fig. 1.—Map showing the relation of the Stanner-Hanter area to the Church Stretton Fault and to the associated outcrops of Precambrian rocks.

Stanner, Worsell, and Hanter on the eastern margin of the great fault], is merely suggested, but the whole of them is probably Archæan."

Cole (1886) contributed a short petrographical paper on Stanner. Its gabbros were designated by him augite-biotite-diorites. He classified the igneous rocks into an Acid Series and a Diabase Series, but did not discuss the age of the rocks, nor their relationship to the surrounding Ludlow sediments.

Frank Raw (1904) believed the Stanner-Hanter massif to be a laccolith of Lower Carboniferous age some 800 feet thick, intrusive into the Ludlow sediments. He was the first to give a general account of the rocks of Hanter Hill.

Professor W. W. Watts (1906) remarked that both Murchison and Cole, in describing the igneous rocks of Stanner, found the majority of their comparisons in Skye, and that, therefore, it was desirable to consider the possibility of these rocks belonging to the olivine-bearing Tertiary group of the latter area.

The most recent reference is that by R. W. Pocock and T. H. Whitehead (1935). They stated that the Stanner-Hanter massif is cut by dykes of acid rock, some of which closely resemble the granophyres associated with the Uriconian rocks north of Lydham. They considered that there is evidence that the Stanner-Hanter rocks are intrusive into Silurian shales. They also pointed out that these rocks are situated within the prolongation of an E.N.E.–W.S.W. belt, which embraces the Carboniferous basalts and dolerites of South Staffordshire, the Wyre Forest, and the Clee Hills, and they suggested that the Stanner-Hanter rocks might also be of Carboniferous age.

II. DISTRIBUTION AND TECTONICS

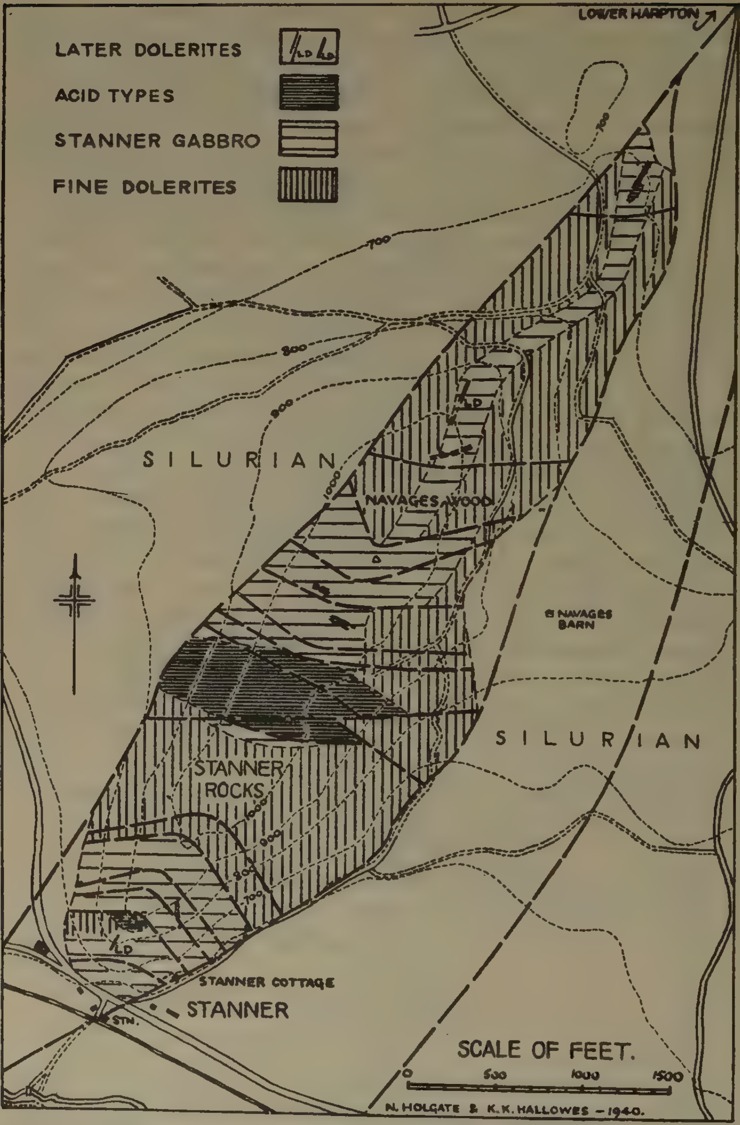
The igneous rocks of the Stanner-Hanter district may be divided into the following groups :—

(*a*) Fine Dolerites
(*b*) Gabbros
(*c*) Acid Types
(*d*) Later Dolerites

(*a*) *Stanner* (K. K. H. &. N. H.)

The Fine Dolerites occupy much of the ridge. At the south-western end of the latter is a complex of Fine Dolerite and Gabbro cut by a plexus of acid veins. In the centre of the ridge, and towards its western margin, a mass of Gabbro occurs, the outcrop of which continues northwards through Navages Wood.

Intruded into the Fine Dolerites and Gabbros are the Stanner



Text-fig. 2.—Geological Map of the Stanner ridge.

"saddle" mass of quartz-porphyry, dykes of quartz-porphyry and aplogranite, and a plexus of acid veins which possibly represent a late phase of magmatic differentiation.

Near the south-west end of Stanner are two small dykes of aplogranite. Each is intrusive into the Gabbros. Further north is the Stanner " saddle " mass of quartz-porphyry, and to the north of this are two parallel acid dykes striking E.S.E.–W.N.W. The southern one is formed of spherulitic quartz-felsite with porphyritic and granophyric structures. The northern one is composed of aplogranite. Still farther north there are three dykes each striking E.S.E.–W.N.W. The two southern ones are composed of aplogranite, the northern one of quartz-porphyry, and all three are intrusive into the Gabbros and Fine Dolerites. Farther north, another dyke, striking N.N.E., is intruded into the Gabbros, and is composed of Later Dolerite. The most northerly dyke is situated near the end of the ridge, and is intrusive into the Gabbros. It appears to strike N. 50° E., but it is badly exposed. One of us (N. H.) has found this dyke to be of a compound nature. All these dykes are so obscured by talus, on the flanks of the Stanner ridge, that it is only possible to give their approximate strike. One of us (K. K. H.) has endeavoured to trace the eastern and western continuations of these acid dykes down the hill flanks and believes, from the rare appearance, through the talus, of occasional small dyke-outcrops, that they possibly continue as far as the Eastern and Western Boundary Faults.

The eastern and western margins of the Stanner ridge appear to be faulted boundaries, since the igneous rocks along the latter are often brecciated, while the adjacent Ludlow sediments are highly disturbed. Moreover, there is no evidence, so far as is known, of an igneous contact with the sedimentary rocks.

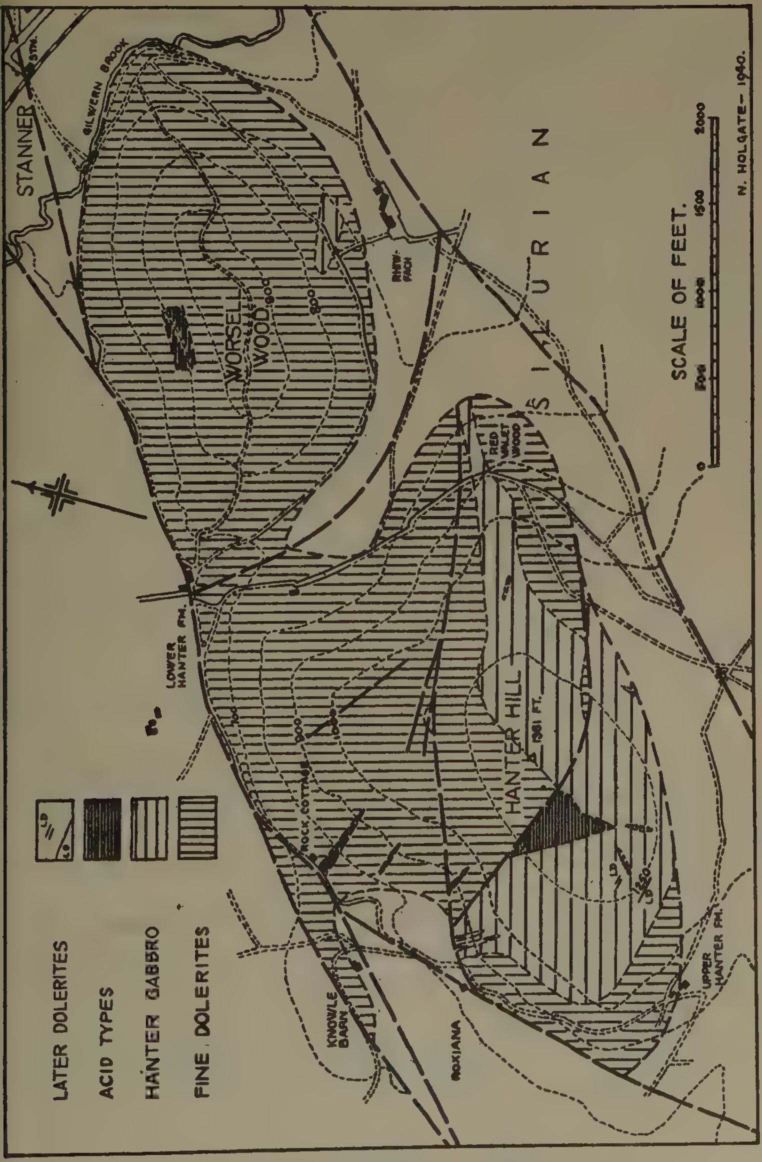
There appears to be a good deal of faulting transverse to the trend of the ridge. This faulting, which has been investigated by one of us (N. H.), is often marked by brecciation as, for instance, the fault which forms the northern boundary of the Stanner " saddle " mass of quartz-porphyry. These faults are also well seen at the south-west end of the ridge. Most of them are evident as notches across the crest, and can be traced on the south and south-east slopes as gullies, which are in some cases well marked, especially above Stanner railway station. To the north-east, however, their surface features are less clear ; and some are so obscure that they have been omitted from the geological map. From their mode of outcrop they appear to hade N.N.E. or S.S.W. in different cases, the hade being, probably, sometimes as much as 30°. The effect of these transverse faults seems to have tended towards the lengthening of the massif along its major axis. This may, possibly, have been caused by compression along its minor axis, as between the jaws of a vice represented by the Eastern and Western Boundary Faults.

(*b*) *Worsell Wood and Hanter Hill* (N. H.)

The Fine Dolerites occupy the greater part of these two hills. The largest area of Gabbros occurs in Hanter, where they are found mainly south of the summit, but a narrow outcrop of them extends north-eastwards to Red Valet Wood; and there are also patches of gabbroic rocks on the northern shoulder above Lower Hanter Farm. On Worsell Wood there is only a small tongue of amphibolized and chloritized gabbro near Rhiw Fâch. Outcrops of acid rocks occur near the summit of Hanter, near Rock Cottage, and on the western flank of Worsell Wood. Aplo-granite and hybrids occur as numerous veins cutting the Fine Dolerites and Gabbros throughout both hills. Four dykes of Later Dolerite are found cutting the Gabbro on the southern slopes of Hanter Hill.

The structure of the Hanter-Worsell hills is interesting and, as in Stanner Rocks, considerable faulting appears to have taken place. Towards the south end of Stanner ridge the rocks enter a zone of intense faulting on E.–W. lines, which brings up successive leaves, of varying thickness, of the Fine Dolerite and Gabbro. This zone of faulting probably continues southwards and determines the valley of the Gilwern Brook, separating Stanner and Worsell Wood. A similar fault may cross Worsell Wood just north of its summit, while a belt of sheared Fine Dolerites suggests another in the valley between Lower Hanter Farm and Rhiw Fâch, dividing Worsell Wood from Hanter Hill.

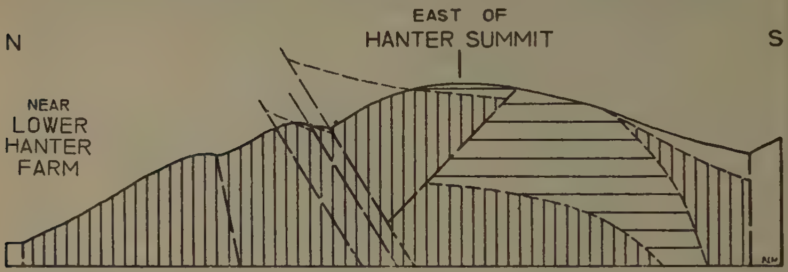
Another fault, recognized by its effect on the topography, extends E.N.E. from near Roxiana, along a shallow gully, and crosses the northern shoulder of Hanter Hill, where it forms a well-marked "shelf". The features suggest that this fault continues in an eastward direction towards Red Valet Wood, but later its position becomes less distinct, although it appears to keep some distance north of the Gabbro boundary, since the granulitized Fine Dolerites close to the latter are undisturbed. The rocks themselves give ample evidence of this fault, particularly in the middle of its outcrop, where the Fine Dolerites are sheared and rotten. This effect can be traced towards Roxiana, but in the other direction the shear zone is unexposed. On the northern shoulder the fault, and a subsidiary on its northern side, define the southern limits of two small masses



TEXT-FIG. 3.—Geological Map of Hanter Hill and Worsell Wood.

of coarse dolerite indistinguishable from the marginal Gabbro exposed farther south-east. These may be portions of the margin of a former extension of the main Gabbro intrusion, brought down by the fault and its subsidiary on their northern side. This probably means that the faults have a downthrow to the north and since they hade to the south they are probably reversed.

Yet another fault crosses Hanter Hill at about 230 feet south of the highest point, in a nearly E.–W. direction. Westwards it turns towards the W.N.W. and follows a gully to the Silurian sediments N.E. of Roxiana. South of the fault the Gabbro is exposed, while on the north side appear the Fine Dolerites. The fault also appears to define the northern margin of the main intrusion of the Hanter type granophyric quartz-porphyry. Across the upper slope of Hanter Hill the fault is ill defined, but it soon reappears as the southern boundary of a lenticular outcrop of the Fine Dolerites. The latter are surrounded by the Gabbro which is exposed on the eastern side of the hill, whence the fault trends E.N.E. enters a marshy gully and soon reaches the sediments surrounding the area. This also appears to be a reversed fault.



TEXT-FIG. 4.—Section across Hanter Hill to show the supposed relations of the Fine Dolerite (vertical lines) and the Gabbro (horizontal lines). True scale; length of section, two-thirds of a mile.

These two main faults on Hanter Hill appear to throw some light on the shape of the Gabbro intrusion. The exposures north of the summit of Hanter Hill suggest that this margin of the Gabbro is the outcrop of the lower surface of the intrusion, and the small faulted patches of the Gabbro farther north support this view. The lenticle of Fine Dolerite exposed on the east of the hill is regarded as another outcrop of the rocks below the intrusion. It is bounded on the south side by a fault which brings down the Gabbro, just as it does on the west side of Hanter Hill. The wider outcrop of the Gabbro on the south of the fault is due to the fact that there the surface topography lies mainly within the thickness of the Gabbro mass. The actual form of the intrusion may be that of an inclined laccolith dipping to the E.S.E. and thinning in that direction. The lobe running downwards near and to the N.E. of Roxiana may represent a feeder through which the magma was intruded.

The western boundary fault of Stanner Rocks appears to continue under alluvium until it reaches the N.W. side of Worsell Wood, where it reappears, to join the S.W. extension of the eastern boundary fault of Stanner, and determines a clear feature along Worsell Wood to Lower Hanter Farm, and thence to near Rock Cottage, where it forks, one branch, marked by a little fault scarp, passing N.W. of the Knowle Barn hillock, and the other, passing in front of Rock Cottage, forming another small feature. As it approaches Knowle Barn the latter branch cuts siltstones, and appears as a slight " crease " in the ground between Knowle Barn and Roxiana. Farther to the S.W. the two branch faults probably reunite and pass up a marked gully on Weythell Moor. A clear feature S.S.W. of Roxiana suggests another fault connected with this system.

East of the hills the features formed by the igneous boundary are usually far from clear, and there are few exposures to give any assistance. East and south of Worsell Wood this is not surprising, as the igneous rocks disappear beneath alluvium and gravels. This is also true of Hanter Hill near Red Valet Wood, but farther S.W. the boundary is against Silurian siltstones, which are found as debris, but, more rarely, in place. It appears likely that here the relation of the Silurian rocks to the igneous complex is a sedimentary one, marked by a plane of unconformity, as the sediments, even when seen close to the Gabbro, are uniformly unmetamorphosed. The same relation between igneous rocks and sediments is suggested in the case of the " bay " of sedimentary rocks between Knowle Barn and Roxiana. It is difficult to see how these features could be explained otherwise. In these parts of the boundary, the igneous rocks probably extend, at no great depth, to the near-by faults.

As in the case of Stanner Rocks, the net result of the faulting within the igneous complex appears to have been such as to increase the ratio of length to breadth in the masses affected. The Stanner-Hanter district is clearly on the south-western continuation of the Church Stretton belt of disturbance.

III. Petrology (N. H.)

(*a*) *The Fine Dolerites*

This is a group of basalts and dolerites which is regarded as the earliest member of the Stanner-Hanter igneous sequence ;

the rocks are typically fine-grained, and are variable in colour. They are usually characterized by small-scale jointing, so that satisfactory hand-specimens are often difficult to obtain. In addition to jointing, these rocks are crossed in places by zones of shearing along which igneous textures are lost, while plane jointing disappears and is replaced by sinuous fracture-surfaces resulting in a rubbly appearance on weathering.

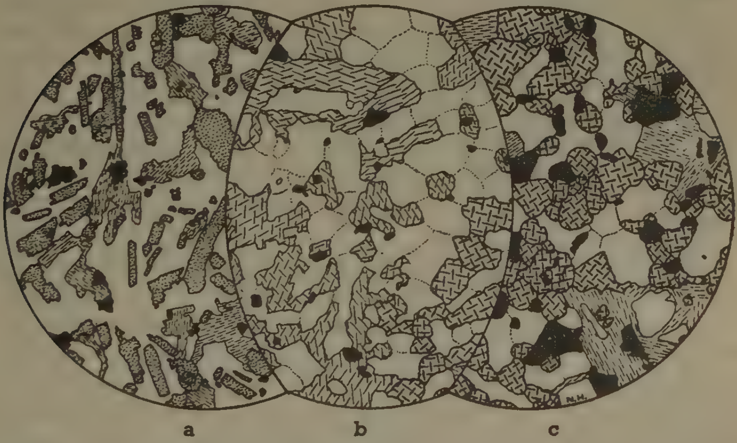
In thin section the rocks are seen to be olivine-free basalts and dolerites with or without interstitial quartz. Textures are variable, some being finely basaltic with intergranular pyroxene and interstitial chlorite, and others somewhat coarse and ophitic. Porphyritic textures appear to be exceptional, for only two cases are known from this group ; one of these has porphyritic plagioclase, so altered as to be indeterminable, while the other has rare chloritic pseudomorphs after a pyroxene.

The Fine Dolerites are very rarely fresh ; many of them show completely albitized plagioclase in association with abundant epidote. The epidote is normally of granular habit and disseminated in the albite ; but locally, as near the summit of Worsell Wood, in the proximity of acid veins, the epidote may be recrystallized into stout prisms in part replacing the plagioclase. The less altered plagioclases of the group appear to be quite basic, corresponding to a basic andesine in most sections. For this reason the rocks are regarded as having been, originally, true calc-alkaline dolerites and basalts.

The pyroxenes may be of granular or ophitic habit, and appear to be normal augites with only a faint absorption colour, but owing to the small grain-size of the rocks no confirmatory measurements have been made. The pyroxenes may be fresh, and associated with only minor quantities of iron ores, which appear to be original. More commonly they are replaced in some degree by pale green amphiboles, the appearance of the latter being accompanied by much iron ore in the rock. In other cases the pyroxene has been replaced by chlorite, the amount of iron ores in the rock then remaining subsidiary. Owing to the very fine grain of many of these rocks, and the obscurity of their secondary minerals, it has not been found possible to study the changes in detail.

There are also quartz-dolerites rather coarser than the typical Fine Dolerites. In thin section they are quite distinctive in grain-size and in the presence of what appears to be original interstitial quartz, but cannot often be distinguished from the rest of the Fine Dolerite group in the field. While some of the finest members of that group have subordinate quartz, this mineral appears to have been secondary, and is often associated with quartz-veining (e.g. in the Knowle Barn crags). Elsewhere, the quartz is seen to have been introduced on a more intensive scale, while the pyroxene has given place to a green hornblende, the chlorite present being presumably pseudomorphous after biotite. In the coarser types, however, quartz appears to be an original constituent.

The textures of these quartz-dolerites are broadly doleritic though their mineralogy, like that of the other Fine Dolerites, often approaches dioritic owing to the amphibolization of the pyroxene. The plagioclase is often highly epidotized, but in some cases is still an andesine; as the plagioclase is always epidotized to some extent, it is reasonable to assume that the original felspar was more basic in composition. The pyroxene is apparently a normal augite with $Z \wedge c = 50^\circ$. During the course of amphibolization it develops schiller inclusions of ilmenite, and is finally replaced by a pale green amphibole, the iron-ore schiller structures at the same time coalescing to form skeletal networks at first and, finally, more or less equiaxial grains. It has not been found practicable to study these changes more closely, owing to the fibrous, felted habit of the secondary amphibole.



TEXT-FIG. 5a.—Epidotized and chloritized Fine Dolerite, from small clearing S.W. of summit cairn, Worsell Wood. × 20.
TEXT-FIG. 5b.—Amphibolized granulitized Fine Dolerite, close to Gabbro margin S.W. of Red Valet Wood, Hanter Hill. × 20.
TEXT-FIG. 5c.—Granulitized Fine Dolerite, close to N.W. margin of Gabbro on shoulder above Red Valet Wood, Hanter Hill. × 48.

(*b*) *The Gabbros*

The Hanter and Stanner Gabbros can be treated together and, although their outcrops are now separated, they probably originated as a single mass. In the field they are characterized by a massive habit and a large-scale cuboidal jointing. Away from the margins the rock is of coarse texture, and locally assumes a pegmatitic habit in which poikilitic crystals of the pyroxene may be as much as 6 inches long. Even in the less coarse types, the continuity of pyroxene cleavages shows that the individual crystals are commonly an inch or more across. Towards their margins, however, the gabbros become finer in grain.

When fresh and unaltered the rock is a quartz-free gabbro, in which no other minerals than plagioclase and a diallagic augite are represented. The plagioclase is a basic labradorite (An_{66} in one section), and not noticeably zoned; it bears a poikilitic relation to the diallage, which has $Z \wedge c = 52°$ and $+2V = 52°$. Commonly, however, the pyroxene has suffered a high degree of amphibolization, and may be entirely replaced. At the same time the plagioclase tends to be albitized, with the separation of much epidotic material. Apatite, in stout prisms, becomes a notable accessory.

The diallage shows a number of different modes of amphibolization, the several products of which may be present together in any one thin section. The diallage may appear as relics surrounded by a hornblende rim, in which the inner parts are brown in colour and the periphery green. This form of amphibolization is not accompanied by any separation of iron ores. The brown hornblende is moderately pleochroic, with X = pale straw, Y = pale brown, and Z = brown, $Z \wedge c = 15°$ and $-2V = 78°$. This appears to be converted to a green hornblende with moderate pleochroism: X = pale straw, Y = yellowish green, and Z = sea-green, while $Z \wedge c = 18°$ and $-2V = 73{\cdot}5°$.

A second mode of alteration is that in which the diallage is replaced by a weakly pleochroic pale green hornblende with X = faint straw, Y = pale yellow-green, and Z = pale bluish green, while $Z \wedge c = 18°$ and $-2V = 72°$. Its appearance is distinctly different from that of the green hornblende previously mentioned; it differs also in that its appearance is associated with an abundant development of iron ore in the form of schiller-structures in the affected diallage. As amphibolization proceeds the schiller structures become modified to bizarre skeletal forms, and finally coalesce as more or less granular masses included in the hornblende.

A third mode of alteration of the diallage, which often affects the relics of pyroxene remaining from the diallage → brown hornblende → green hornblende conversion, gives a pale green actinolite, pleochroic from colourless to a very pale green, with $Z \wedge c = 15°$ and $-2V = 88°$; and is accompanied by a considerable separation of iron ores. Finally, the diallage may suffer alteration to a green penninite.

Over a small area south of the summit of Hanter Hill, the altered gabbro has undergone changes distinct from those already mentioned. The plagioclases are completely albitized, considerable quantities of epidote being present in the rock. The diallage, too, has been entirely altered, giving single crystals or felts of a pale green actinolite with X = colourless, Z = very pale blue-green, $Z \wedge c = 16{\cdot}5°$ and $-2V = 80°$. Another mineral, of porphyroblastic habit, occurs in sporadic knots about a centimetre across. It is pale grey in colour, with strong pleochroism, E = pale slate grey, and O = slate blue-grey to a deep slate-blue, variable in fairly well-defined zones. Birefringence is moderate, giving first order colours; extinction is straight on cleavages, in the vertical zone. A section cut normal to the crystallographic axis *c* shows a centred uniaxial negative figure in convergent light. The mineral appears to be a blue tourmaline.

As the margins of the Gabbro are approached the rock becomes gradually finer in grain, and the poikilitic often passes into a medium-grained ophitic texture. As in the coarser types, the original mineralogy is often obscured by amphibolization, while locally the incoming of acid material has given contaminated types, such as the "mica dolerite" of Stanner Quarry, with acid patches and common biotite. The acid material appears to be related to the aplogranite type described later; it shows many of the same characters, and tends to be contaminated in the same way.

(*c*) *The Acid Types*

These are remarkably varied, and, while they cannot be regarded as contemporaneous, they appear to occupy a common position in the sequence of the Stanner-Hanter complex. The following types can be recognized :—

(i) Aplogranite and hybrids
(ii) Granophyric quartz-porphyry of Hanter Hill
(iii) Quartz-porphyry of Knowle Barn
(iv) Porphyritic felsite of Worsell Wood
(v) Quartz-porphyry of Navages Wood

(vi) Quartz-porphyry of Stanner Rocks
(vii) Quartz-porphyry of the old quarry S.W. of Lower Harpton.

No indication of their relative ages has been obtained, as the cutting of one type by another has never been observed. The close similarity of the quartz-porphyries in the hand renders it extremely difficult to distinguish between them.

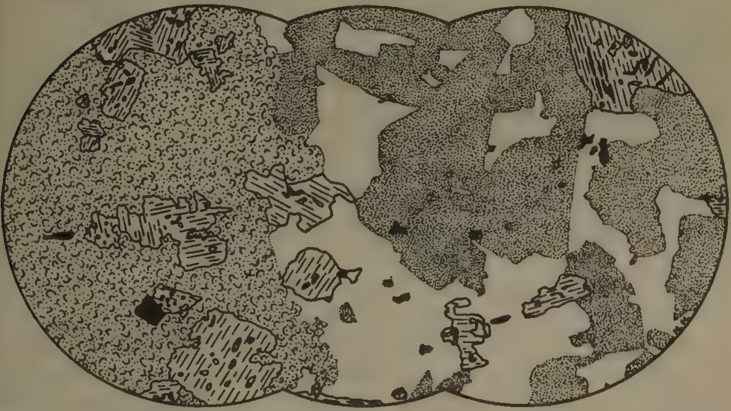
(i) *Aplogranite and Related Hybrids*

These occur almost exclusively as small veins intrusive into any or all of the basic types with the exception of the Later Dolerites. Only in one or two localities can the development be said to deserve the name of dyke-like bodies; this occurs at a patch bare of trees towards the south-west end of the top of Worsell Wood, and again about 900 feet south of the main top of Stanner Rocks, at the 900 ft. contour. In the quarry at Stanner station the type appears as obscure veinings, impregnations, and apparently isolated pools in a modified gabbro which has often been referred to as a mica-dolerite.

The Aplogranites are typically of a pale cream colour, though the derived hybrids are darker, and spotted with chloritic pseudomorphs after biotite. A small-scale jointing, similar to that seen in the Fine Dolerites, is generally developed. The types are of widespread distribution in the Stanner-Hanter area, but owing to their considerable variation it was not until they had been studied in thin section, and re-examined in the field, that it was realized that they constitute a group whose present mineralogy and textures are the result of a process of hybridization in which there was an interchange of material between an aplogranite magma and the country rocks into which it was intruded.

The most acid types are largely granitic in texture, with sporadic coarsely granophyric areas. The minerals present are quartz, microcline-microperthite, plagioclase, and subsidiary chlorite and sericite; more rarely, the microcline-microperthite may be displaced, wholly or in part, by a normal orthoclase-microperthite. The similarities shown by the type to rocks from other areas is dealt with elsewhere in this paper. Some apatite is often present, and locally a greenish biotite in small amounts. The quartz occurs as allotriomorphic patches, and as occasional granophyric inter-growths with microcline-microperthite. The latter also occurs as hypidiomorphic plates, and is clouded by sericitic alteration products. The plagioclase shows somewhat embayed lath-shaped individuals well twinned on the albite law. Their present composition is close to pure albite, but the presence of dusty inclusions of epidote suggests that they were originally more calcic. The chlorite is a rather strongly coloured penninite, pleochroic from pale straw to rather strong green, with brownish pleochroic haloes, and showing " ultra-blues " between crossed nicols. It is of micaceous habit, probably replacing biotite, and is intergrown with a sericitic mica.

The type just described is fairly common in the area, but in addition there has been found a series of types grading from it, with an increasing proportion of plagioclase, chlorite pseudomorphs after biotite, and a corresponding decrease in microcline-microperthite. The textures show, at the same time, a gradual change in which the granophyric tendency fails, and in which the original granitic texture tends towards a micro-monzonitic one; in this the plagioclase becomes idiomorphic and is set poikilitically in large plates of microcline-microperthite and of quartz, neither of which shows idiomorphic boundaries towards the other.



TEXT-FIG. 6.—Junction between aplogranite hybrid and basic country-rock, showing chloritic pseudomorphs after porphyroblastic biotite included in the Fine Dolerite country-rock (left) and passing into the aplogranite hybrid. From a xenolithic aplogranite hybrid, Fine Dolerite outcrop E. of summit, Hanter Hill. × 13.

A typical section, from an acid vein cutting the Gabbro on the north-east shoulder of Hanter Hill, shows the first stages of this change, and a granitic texture is present in some parts of the slide. A more advanced stage is seen in the vein cutting the Gabbro on the ridge south-west of the southerly summit of Stanner Rocks. Here quartz and microcline-microperthite are still fairly abundant, but in the form of poikilitic plates enclosing idiomorphic laths of albitized plagioclase with clouds of epidotic inclusions. This texture is truly micromonzonitic, but considering the rock as a whole the effect is spoiled by the presence of large chloritic pseudomorphs after biotite, a little of the latter remaining unaltered. The chlorite is again a penninite, but it is only slightly pleochroic in greens. In addition to the common micaceous habit, a spherulitic chlorite appears locally, forming patches in the pseudomorphs. Lenticles of epidote are distributed along the cleavages of the pseudomorphs, and with them one or two small patches of a colourless or very pale actinolite which may have been floated off from the country-rock. There are also small patches of quartz included in the pseudomorphs, and some ilmenite.

Another section, taken from a specimen collected close to that just described, and possibly from the same vein, is even richer in chloritic pseudomorphs after biotite. The texture is clearly micromonzonitic, the quartz and microcline-microperthite plates being crowded with plagioclase laths. The chloritic pseudomorphs are again characterized by the presence of inclusions, suggesting the origin of the crystals as porphyroblasts formed in a solid or almost solid environment, and that they were floated off from the rock in which they grew, on its mechanical disruption by the intruding aplogranite magma. An examination of the hybrid and its contact with the country-rock supports this view. The country rock is always a doleritic or gabbroic rock-type, and in it, close to the edge of an acid vein, chlorite pseudomorphous after biotite, of porphyroblastic habit and including, poikiloblastically, lenticles of epidote and of quartz, is very common. The actual junction of acid and basic types has a frayed appearance, and the acid type includes chlorites similar to those remaining in their basic parent rock. It is often noticeable, too, that the chlorites decrease in number away from the basic material, whether this be wall-rock or xenolith. It is, therefore, probably safe to assume that these crystals grew in the wall-rock and xenoliths and were dispersed in the invading acid magma as a result of the mechanical disruption of the basic host.

The contamination of the acid types appears to have been dominated in its early stages by reciprocal reaction between the invading aplogranite magma and the basic wall-rock and xenoliths. While the quantities of quartz in the hybrids relative to the rest of the felsic minerals seems to have remained more or less constant, the potash felspar shows a decrease and is replaced in an increasing degree by a sodic plagioclase which is now albitized. In some types, especially where the basic rock involved was one of the Fine Dolerite group, the hybrid may show little or no accession of ferromagnesian constituents ; in such cases the present condition of the hybrid has been controlled largely by reciprocal reaction. The result of these transferences, as seen in the rocks themselves, has been to convert the acid type into an aplitic monzonite, to produce biotite from the pyroxene and amphiboles, and a more acid plagioclase from the labradorite, of the basic type. From the point of view of the acid type, therefore, the process was one of endocontamination, as defined by Nockolds (1935).

In later stages, however, the xenoliths and wall-rock began to contribute solid material, of which only the chlorite (after porphyroblastic biotite) is traceable in the hybrid. This phase of contamination, which appears to have begun earlier in the cases where the wall-rock and xenoliths were of the Gabbros than where the Fine Dolerites were the basic types concerned, constitutes, again from the points of view of the invading acid material, the process which has been described by Nockolds (*loc. cit.*) as exocontamination.

Finally, it may be remarked that the aplogranite and hybrids never show any signs of chilling against the country-rock. This, and the fact of the widespread development of the acid veins, suggest that the country-rocks, the Fine Dolerites and the Gabbros, were at a fairly high temperature when the aplogranite magma was intruded. Two explanations can be offered to account for this : (1) that the aplogranite and hybrids are a visible minor intrusive phase connected with an acid mass situated at greater depths, but nowhere exposed ; or (2) that the aplogranite magma was intruded while the country-rocks were still hot from the intrusion of the Gabbros. Indeed, it is possible that both of these conditions were simultaneously fulfilled. The origin of the aplogranite magma is itself uncertain, though the total absence of quartz from the typical Gabbro types may indicate that the acid material was derived from an independent source. It does not appear to have arisen by a process involving the mobilization of pre-existing quartzose material by the gabbro intrusion, as no pre-gabbro acid material is known in the Stanner-Hanter complex. Probably genetically associated with the aplogranite type are a few small granite-pegmatite veins on the western side of Hanter Hill. One, near Roxiana, is about 6 inches wide, while another, which has been sectioned, occurs farther uphill towards the north-east. This shows a coarse graphic intergrowth of quartz with microcline-microperthite, occasional crystals of an acid plagioclase being developed in addition. Small amounts of chlorite and epidote occur disseminated in the vein.

(ii) *Granophyric Quartz-porphyry of Hanter Hill*[1]

This rock-type has been recognized as forming at least four intrusive masses on Hanter Hill, and a large part, if not the whole, of the felsitic mass which cuts across the middle of the ridge of Stanner Rocks. The rock is creamy-yellow in colour in the hand specimen, and not obviously porphyritic, but spotted with small nests of micaceous material which weather out as cavities, giving the rock a pitted appearance. The rock is highly jointed, and breaks readily into angular fragments.

In thin section the rock is quite distinctive. It is porphyritic, with quartz phenocrysts showing the habit of the high temperature modification, each being completely surrounded by radiating micropegmatite; phenocrysts of an acid plagioclase are less common. The groundmass consists largely of areas of quartz-felspar micropegmatite, varied by small patches of quartz-felspar mosaic and roughly rectangular areas of radiating sericitic material, possibly pseudomorphous after a porphyritic felspar.

In the Stanner Rocks locality the rock appears to pass laterally into a type with a finer-grained groundmass. Whether this is a chilled marginal phase is not clear, though no intrusive relation to the Hanter type proper has been proved owing to the close similarity of the two rock types in the hand.

A thin section of this latter type shows a porphyritic acid plagioclase (probably albite) enclosing granules of epidote; quartz is less common as phenocrysts, and the presence of a glomeroporphyritic graphic intergrowth of quartz and an acid plagioclase marks a divergence from the true Hanter type. The groundmass is made up of small sutured quartz patches and tiny felspar laths, with occasional grains of epidote, sericitic spots and patches of secondary calcite.

(iii) *Quartz-porphyry of Knowle Barn*

This type is of considerable interest in spite of its small observed outcrop. It occurs as a single small vein cutting the Fine Dolerite on the south-western side of Knowle Barn Crags at a point about 120 feet W.S.W. of the farm buildings. The vein is about

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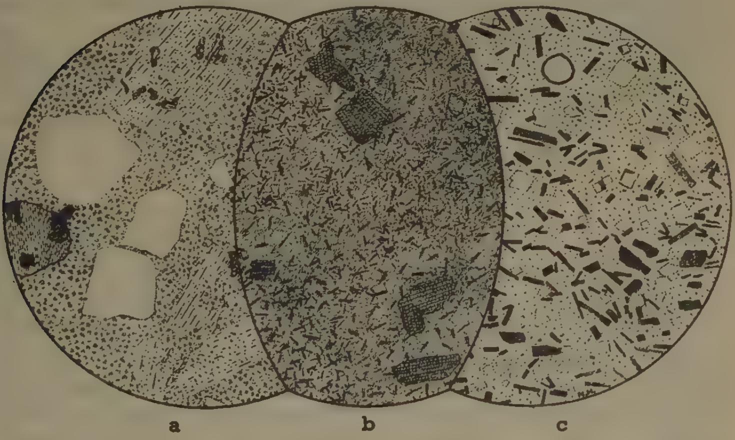
[1] N. H. wishes to acknowledge his indebtedness to K. K. H. for additional information relative to the presence of the Hanter type of granophyric quartz-porphyry among the rocks of the Stanner "saddle" acid mass.

6 inches wide and is elongated in a N.W.–S.E. direction ; it is not seen on the north-west side of the knoll. The rock is of a dirty cream colour, fine in grain, and with inconspicuous quartz phenocrysts. It shows a network of darker greyish lines, as though in the early stages of brecciation, and breaks up readily into irregular fragments.

In thin section the rock is seen to be markedly porphyritic, the porphyritic elements being quartz and an acid plagioclase. The porphyritic quartz occurs very sparingly, though it may reach up to 2·5 mm. across and shows no signs of corrosion. The porphyritic plagioclase occurs rather more abundantly, individuals reaching 1·25 mm. × 0·4 mm. It is poorly twinned, simple Albite or Carlsbad twins being usual. The crystals are much altered, with the production of sericitic material, and appear to have a composition close to pure albite.



Text-fig. 7a.—The Quartz-Porphyry of Stanner Rocks, from edge of summit clearing, E. of southerly summit, Stanner Rocks. × 12.
Text-fig, 7b.—The Porphyritic Felsite of Worsell Wood, from large crags at 800 ft. O.D. on N.W. slopes of Worsell Wood. × 17.
Text-fig. 7c.—Garnetiferous Quartz-Porphyry of Knowle Barn : groundmass, to show garnet, and habit of groundmass quartz. From S.E. face of Knowle Barn crags, west of Hanter Hill. × 40.

The groundmass consists of quartz, plagioclase, rare pink garnet, and possibly some potash felspar. Quartz is abundant and striking in numerous idiomorphic square, hexagonal and triangular sections, suggesting the high temperature habit, up to 0·1 mm. across. The plagioclase of the groundmass is perhaps a little more abundant than the quartz: it also is idiomorphic, in laths about 0·15 mm. × 0·02 mm.; it is poorly twinned, and rendered turbid by sericitization, and appears to have a composition close to pure albite. The rare garnet occurs as rounded crystals, sometimes unaltered, but frequently much cracked and showing incipient alteration to a pale chlorite. The garnet is pale pink in colour, has a refractive index of $1{\cdot}805 \pm 0{\cdot}0005$, and a specific gravity of 3·91 (determined by suspension in Clerici solution). From Winchell (1933, fig. 93, p. 176, and fig. 98, p. 180) the composition corresponding to these values is Py_{31} Al_{46} And_{23}. The rock, though veined with quartz and slightly sheared in places, does not appear to be in general affected by strain, and it appears probable that the garnet is of pyrogenetic origin.

The interstitial material of the groundmass is finely crystalline and appears to consist of quartz and alkali felspar. Scattered through it are small amounts of biotite, chlorite, and epidote.

(iv) *Porphyritic Felsite of Worsell Wood*

This type is known to occur in two localities only: it forms a line of crags, not marked on the O.S. 6-inch sheet, at about 800 feet O.D. on the north-western slopes of Worsell Wood. It is also seen on Stanner Rocks, at the south-eastern tip of a crag low on the south-eastern slope opposite the gate opening on a track leading to Dunfield. Only in the latter locality can any idea of the relations of the type with the Fine Dolerites be gained: the felsite appears to have a dyke-like habit, trending roughly N.E.–S.W. This may also be true of the Worsell Wood mass, but there no contacts with the surrounding types are visible.

The rock is very fine-grained as seen in the hand-specimen, and has a patchy grey colour: the porphyritic character is not obvious. As in the case of the other acid types, the rock is highly jointed. In section, the rock is obviously porphyritic, with idiomorphic plagioclase in single crystals or in groups. Their composition is apparently Ab_{94} An_{6}, but the presence of disseminated zoisite and epidote suggest that the plagioclase was originally more calcic. The groundmass shows indefinite laths of an indeterminate felspar, with abundant spherulites and micropegmatite patches. Lath-like sections of a chlorite are common but variable in frequency: a few larger flakes and vermicular patches are scattered through the rock. Iron ore is rare, but patches of leucoxene probably represent original ilmenite.

(v) *Quartz-porphyry of Navages Wood*

This type is only known from the more southerly of the small crags S.S.E. of the old quarry, marked on the O.S. maps, S.W. of Lower Harpton. The type superficially suggests a fine granitic or microgranitic character ; it is normally pale brown in the hand, but may weather to more reddish tints. Jointing is developed on a considerable scale, while specimens from the most southerly exposure show signs of brecciation. In thin section the texture is porphyritic, with phenocrysts of plagioclase and of quartz. The porphyritic plagioclase is twinned on the albite and pericline laws, is somewhat clouded by exclusively sericitic alteration products and appears to have a composition close to pure albite. The quartz individuals are small, and somewhat rounded by resorption ; each is surrounded by a rim of untwinned, altered felspar, apparently albite. The groundmass consists of a felt of stumpy laths of albite, with patches of microperthite and interstitial quartz pools. Patches of a green chlorite, close to cracks in the rock, appear to be of secondary origin.

(vi) *Quartz-porphyry of Stanner Rocks*

This type is known from the Knowle Barn exposures, and from the " saddle " between the two summits of the Stanner ridge, where it cannot be differentiated in the field from the Hanter type of quartz-porphyry. In the hand, the Stanner type varies from a greyish to a creamy colour like that of the Hanter type. It is highly jointed and fractures irregularly, some brecciation being observable locally. In thin section the rock shows abundant porphyritic quartz and plagioclase and some chlorite set in a microcrystalline groundmass of granular quartz and an alkali felspar. The quartz phenocrysts are large and rounded, and may be in groups of two or three crystals, measuring up to 2 mm. across. The plagioclase phenocrysts are of albite or albite-oligoclase and are locally replaced by flaky sericite. The chlorite is a penninite of micaceous habit, possibly replacing original biotite, and associated with it are grains of epidote and opaque white patches of leucoxene.

(vii) *Quartz-porphyry of the Old Quarry S.W. of Lower Harpton*

This type forms small crags east of the old quarry S.W. of Lower Harpton, and occurs on Stanner Rocks, at the brow of the hill, S.W. of the southern summit. In neither case can the relations of the type to the surrounding rocks be made out, though probably intrusive into the Gabbro and Fine Dolerites.

The rock is pale brownish in colour, with recognizable phenocrysts of quartz ; as usual, jointing is well developed. In thin section the material from the " Harpton " quarry is much altered, but that from Stanner Rocks proves to be comparatively fresh. Its texture is porphyritic, with idiomorphic though often rounded quartz phenocrysts. Porphyritic albite is rarer, the separation of sericitic and epidotic material suggesting that it was originally a more calcic plagioclase. Chlorite occurs in large crystals, of a micaceous habit ; it is intergrown with a sericitic mica, and may be secondary after biotite. In other cases the chlorite is of a vermicular habit, perhaps infilling vesicles in the rock. The groundmass consists of equigranular quartz and what appears to be orthoclase, along with a rarer acid plagioclase.

(*d*) *The Later Dolerites*

These embrace three distinct petrographic types. The first two, both from the south-western slopes of Hanter Hill, are dolerites or basalts, and are little altered. Both have a dyke-like form, cutting the Gabbro, and trend N. 122° E. The two most southerly dykes are somewhat irregular, never more than a foot wide, and can only be traced for about 20 feet along their strike. They are fine in grain, obviously porphyritic and show narrow chilled margins against the Gabbro. In section, augite phenocrysts are seen to form some 10 per cent of the rock. They are fresh and of a pale neutral tint, and have $Z \wedge c = 46°$, and $+ 2V = 50°$. The groundmass has a finely basaltic texture, with plagioclase laths, granular augite, chlorite, ilmenite, and leucoxene. The plagioclase is much altered, with indistinct twinning. In one or two parts of the slide there are very small rounded grains of a reddish, isotropic, highly refractive mineral, probably a spinel.

About 150 feet north of these dykes is a second pair, with a similar trend, which weather out to give narrow slots in the Gabbro country-rock. Owing to weathering, chilled margins could not be recognized, nor could a porphyritic character be made out. In section the rock is sparsely porphyritic, with a groundmass considerably coarser than that in the previous type. The plagioclase is moderately fresh, but owing to its poor twinning no indication of its composition has been obtained. The pyroxene is of a pale neutral tint, usually intergranular, but sometimes clearly ophitic. The maximum angle $Z \wedge c$ measured was 43°. Ilmenite, originally abundant, is now largely replaced by granular leucoxene. Chlorite has an intersertal habit, but occasionally replaces sparse porphyritic elements, probably of pyroxene, though none remains unaltered.

Lastly, a type from the ridge of Stanner Rocks, north-east of the main top, again cutting Gabbro, is non-porphyritic and has a typical ophitic texture much coarser than that of the last type. The pyroxene has a faintly purplish tint, with $Z\wedge c = 43°$ and $+2V = 49°$. The plagioclase is poorly twinned and somewhat decomposed, and it has not been possible to determine its composition. Iron ore is abundant, and in more altered material the pyroxene is replaced by a yellow chloritic material of unusually high birefringence.

The evidence of the age relations of the Fine Dolerites and the Gabbros is unmistakable. In various places, notably the northern brow of Hanter Hill, and on the Gabbro boundary east of the main summit of Stanner Rocks, the marginal Gabbro is clearly xenolithic, and carries masses of the Fine Dolerite which forms the country-rock of the intrusion. Further evidence is afforded by the distinct granulitization suffered by members of the Fine Dolerite group at or near the boundaries of the Gabbro intrusions. This is particularly well seen at the Gabbro-Fine Dolerite contact a few yards south-west of the summit of Hanter Hill, where, in spite of subsequent amphibolization, the superimposed granulitic texture of the country-rock is clear. The Fine Dolerites on the north-eastern ridge of Hanter Hill, close to the Gabbro margin, are similarly granulitized, with dusty felspars such as are considered by MacGregor (1931) to be indicative of thermal metamorphism. Sections from other localities close to the Gabbro margin show earlier stages of granulitization, while some masses of the Fine Dolerite which in the field suggest the effects of baking by the near-by Gabbro show, in thin section, characters which are quite inconclusive. The positive evidence is, however, in favour of the post-Fine Dolerite age of the Gabbros.

The relation of the Acid Types to the Fine Dolerites and the Gabbros is clear, since the first always cut the other two types in localities in which the relations can be made out.

Their relation to the Later Dolerites is less clear, as the members of this group are never seen to cut or be cut by the Acid Types. In this case more indirect evidence must be used. As already described, the Fine Dolerites and Gabbros are commonly affected to a greater or less degree by a process of epidotization in which the plagioclase felspars become albitized.

This process is also evident in the Acid Types, particularly in the aplogranite and hybrids with which it appears to be associated. In spite of the widespread and often intensive epidotization of, and the abundant development of acid veins in, the Gabbro at the most southerly locality in which the Later Dolerites are seen on Hanter Hill, the latter show no signs of epidotization, and may therefore belong to the post-epidotization stage. Consequently the Later Dolerites are regarded as the youngest group of igneous rocks exposed in the Stanner-Hanter complex.

IV. THE AGE OF THE STANNER-HANTER IGNEOUS ROCKS

(K. K. H. & N. H.)

This district is situated in the south-western continuation of the Church Stretton belt of disturbance and the presence of Longmyndian grits and conglomerates in Old Radnor Hill recalls the relation in South Shropshire between the outcrops of the Longmyndian and Uriconian rocks. It may also be noted that the quartz-porphyry dykes strike across the trend of the Stanner-Hanter ridge.

The idea occurred to one of us (K. K. H.) that the pebbles of igneous rock in the Longmyndian conglomerates of Old Radnor Hill (Garwood and Goodyear, 1918), might be found to be similar to some of the Stanner-Hanter igneous rocks, and a number of these pebbles were collected and sliced. Professor Garwood kindly lent one of us (K. K. H.) a number of thin sections of the pebbles collected by him in 1917, when he was mapping the Precambrian grits and conglomerates of Old Radnor Hill, immediately to the west of the Stanner-Hanter district.

The above-mentioned sections were compared with sections of the Stanner-Hanter igneous rocks, and it was found that the pebbles of granophyric aplogranite, quartz-porphyry, and aplogranite with microcline-microperthite are very closely similar to rocks known in the Stanner-Hanter mass, both the Navages type and the felsitic modification of the Hanter type of quartz-porphyry being apparently represented; another quartz-porphyry pebble appears to be identical with the Stanner type. There are many pebbles of aplogranite with little or no microcline-microperthite, and this type also appears to be represented locally on Hanter Hill.

It would appear possible that some of the Longmyndian conglomerates of Old Radnor Hill were derived from the denudation of igneous rocks such as are now exposed in the Stanner-Hanter area. Furthermore, some of these Stanner-Hanter rocks recall the intrusive rocks known in the Precambrian volcanic series (Uriconian) of Shropshire, which appears to confirm Callaway's view that some parts of the Uriconian may be older than the Longmyndian in South Shropshire. It may be noted that Cobbold and Whittard's work (1935) on the Helmeth Grits leads to a similar conclusion.

Some of the rocks in the Stanner-Hanter mass, particularly the granophyre and aplogranite, are closely similar to the intrusives in the Uriconian volcanic rocks of the Wrekin. The coarser members of the Later Dolerites resemble a dolerite exposed at the south end of Caer Caradoc, particularly in the appearance of its pyroxene.

On the south-western flank of the Stanner ridge an excavation was made on the site of a number of boulders of felspathic quartzite, in view of the possibility of finding the rock in place beneath. The excavation established that the boulders were derived from a boulder-clay bearing abundant quartzite fragments ; the " solid " beneath was seen to be a fine dolerite. The presence in the quartzite of a small form of *Pentamerus oblongus* and a coral cf. *Petraia* suggests that it is of Upper Llandovery age. The provenance of the quartzite is, however, unknown.

The dolerites of the Stanner-Hanter area are unlike the dolerites of other areas in the Welsh Border in that they do not contain olivine or pseudomorphs after olivine. The dolerites of Baxter's Bank, Radnorshire (Roberts, 1927), are intruded into Lower Bala rocks, and are characterized by the presence of serpentinous pseudomorphs after olivine. The basic intrusions of Gelli Hill, Radnorshire (Smith, 1918), are also olivine-dolerites, and are said to be of post-Llandovery age. Similarly, the basic intrusions of Llanwrtyd, Breconshire (Stamp and Wooldridge, 1923), carry olivine. The Carboniferous dolerite of the Clee Hills contains olivine and analcite. It thus appears that the Stanner-Hanter dolerites and gabbros cannot be matched with any of the basic intrusives in the Welsh Borderland which are known to be later than the Precambrian. Furthermore, there appears to be no evidence of an intrusive contact between the igneous rocks and the surrounding Ludlow sediments.

It would seem, therefore, that in this district we have an area of igneous rocks which belong to the Precambrian.

V. SUMMARY AND CONCLUSIONS (N. H. & K. K. H.)

The igneous rocks of the Stanner-Hanter district are regarded as part of a larger unexposed development of intrusive types. They are brought to the surface along the line of the Church Stretton belt of disturbance. From their condition, petrographic characters, and similarity to other Precambrian intrusives of the Shropshire region, and from the occurrence of closely comparable rock-types among the pebbles of the Longmyndian conglomerates of Old Radnor Hill, they are regarded as of Precambrian age. They may, locally, be overlain unconformably by sediments of Ludlow age, but direct evidence of this is lacking.

The igneous sequence began with the intrusion of the fine dolerites, probably in the form of successive thin sheets or sills. The country-rock into which these were intruded has not been recognized. Then followed the intrusion of the gabbros, possibly in the form of a laccolith. This was followed by the injection of the aplogranite magma and the production of its associated hybrids. Late-stage activity on the part of this magma may have caused the widespread epidotization and amphibolization which is so characteristic of the earlier basic types. The other acid types (quartz-porphyries) and the Later Dolerites were next intruded ; the relative ages of these are unknown.

The rock-types found are fairly normal ; the basic types, though much altered, are recognizable as olivine-free gabbros and dolerites. The acid types are similarly normal, except for the garnetiferous quartz-porphyry of Knowle Barn. The aplogranite and its hybrids are of interest in that gradations are found between the most acid types, which appear to represent the original magma, and hybrid monzonitic types rich in biotite.

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A New Genus of Trilobites and other Fossils from Girvan

By F. R. C. Reed

(PLATE V)

I

A SMALL series of fossils, recently collected by Mr. James L. Begg mainly from the Ordovician beds of Girvan and sent to me for examination, include some interesting specimens amongst which is a species of trilobite which must be put in a new genus. My thanks are due to Mr. Andrew Ferguson, of the Geological Department of Glasgow University, for making the photographs of the specimens.

II

Description of Species

TRILOBITA

Family Cheiruridae

Pliomerella serotina gen. et sp. nov. Pl. V, figs. 1, 2

Head-shield transversely semicircular, very gently convex from side to side and from back to front. Glabella subquadrate, as broad as long, slightly convex, composed of two pairs of lateral lobes and a frontal lobe ; anterior end of glabella obtusely angulated ; sides of glabella nearly straight, very slightly arched, subparallel ; frontal lobe transversely subrhomboidal, about half the length of the glabella ; anterior lateral furrows arising at lateral angle of frontal lobe, directed slightly backward, long, reaching on each side about two-fifths across the glabella, slightly sinuous ; postero-lateral furrows arising at middle length of the sides of the glabella, horizontal, slightly sinuous, as long as anterior furrows, with inner ends bent slightly forward but not enclosing anterior lateral lobes which have an elongated wedge-shape ; posterior lobes transverse, suboblong, not enclosed. Neck-furrow strong, arching forwards in the middle ; neck-ring rounded. Axial furrows strong, forming a gentle outward curve. Anterior border of head-shield narrow, marked off from glabella by a strong furrow. Fixed cheeks with long narrow anterior wing, the anterior branch of the facial suture nearly parallel to the axial furrow, the posterior branch bending out nearly at right angles at a level a little behind the postero-lateral furrow of the glabella and curving back to cut the lateral edge or posterior angle of the head-shield. Eye-lobe long, narrow, smooth, depressed.

Surface of head-shield minutely granulated and bearing some very small, low, widely-separated tubercles.

Dimensions.—Length of head-shield 12·5 mm.; length of glabella 10·0 mm.; width of glabella at base 13·0 mm.; width across frontal lobe *c.* 15·0 mm.; width of fixed cheek at base *c.* 8·0 mm.; total basal width of head-shield (estimated) *c.* 28·0 mm.

Horizon.—Balclatchie Beds.

Locality.—Dow Hill.

Remarks.—The only specimen of this new trilobite consists of part of a head-shield having the glabella and right fixed cheek nearly perfect, and the impression of part of the same specimen. The only species which at all resembles it is *Amphion pauper* Salter (1864, p. 83, pl. vi, fig. 32) from the "Caradoc" of Tramore, Co. Waterford, probably from the beds which the present author described as the Tramore Limestones (*Quart. Journ. Geol. Soc.*, lv, 1899, 729–733). Both our new species and Salter's agree in having only two pairs of lateral furrows in the glabella, but Salter says that the frontal anterior or first lateral furrows are represented in his species by a "faint marking". There is no indication of any kind that such were present in our new species. The shape of the glabella is also different, being in ours much broader and shorter, and the neck-furrow is also strong, instead of weak. The absence of the usual three pairs of furrows, combined with some characters of *Pliomera* (= *Amphion* Salter), seem sufficient to mark off a new genus, for both *Pliomera* and *Pliomerops* have three pairs of furrows. We may note, however, that in *Pliomera insolita* Poulsen (1927, p. 307, pl. xx, fig. 32) which Öpik (1937, p. 116, footnote) suggests belongs to *Protopliomerops*, the anterior furrows are reduced to mere pits. None of the Canadian species of *Pliomera* described by Billings can be considered as closely allied, all possessing important points of difference in the characters of the glabella, and Raymond (1925, pp. 152–3) puts several of them in his genus *Pliomerops*. In *Pliomerops bilirata* Raymond (1925, p. 156, pl. 10, figs. 6, 7) there are only two distinct pairs of lateral furrows, but the first or anterior pair is represented by short straight indentations in the sides of the glabella, and there are several other marked points of difference in the head-shield of that species. The species of *Pliomera* and *Pliomerops* previously described from the Girvan area are completely distinct from our new form and it is therefore unnecessary to compare them. The genotype of *Pliomera* (*Asaphus fischeri* Eichwald, 1825) which Schmidt (1881, p. 191, t. xiii, figs. 1–8) has described in detail, and Öpik (1937, p. 116, t. xix, fig. 4, t. xxv, fig. 5) has further illustrated, has a group of three short furrows in the frontal lobe of the glabella of which the outer ones are usually regarded as representing the normal anterior or first lateral pair ; the two posterior pairs of well marked lateral furrows are oblique and subparallel and show no tendency to enclose a subcuneate lateral lobe, as in our new species. In *Protopliomerops* Kobayashi (1934, p. 568) the cephalon is said to be quite similar to that of *Cyrtometopus* and has three pairs of lateral furrows and many other distinctive features. Öpik (1937, p. 115) would put *Pliomera* and *Pliomerops* in a separate family from the Cheiruridae, and would include the genera *Placoparia* Corda and probably *Diaphanometopus* Schmidt in it, though the relations of the latter and of *Protopliomerops* are not clear, and Kobayashi's remarks on their affinities do not commend themselves to me. In none of these genera can our new Girvan species be satisfactorily included, so that the new generic name *Pliomerella* is suggested. If it were not for the possession of only two pairs of lateral furrows on the glabella, the shape of the glabella and course and length of these lateral furrows in our specimen would suggest the peculiar genus *Heliomera* Raymond, of which the only known species is *H. sol* (Billings) which Raymond (1910, p. 77, pl. xviii, fig. 12) describes from the Chazy formation of New York as well as from Newfoundland where the original specimen was obtained.

Family Illaenidae

Illaenus oblongatus (Angelin) var. nov. *exstans* Pl. V, fig. 7

One small pygidium agrees closely with *I. oblongatus* (Ang.) (Holm, 1886, p. 117, t. viii, figs. 1–13) and less closely with *I. schmidti* Nieszk. (Holm, 1886, p. 107, t. v, figs. 1–20) except that the axis is more convex than in either of these species, rising strongly and suddenly above the lateral parts of the pygidium, though it has the same short triangular shape, forming nearly an equilateral triangle, and it is defined by an acutely pointed apex, which reaches to about a third the total length of the pygidium. There are, moreover, faint traces of 4 or 5 tranverse rings on its surface. The inner half of each lateral lobe is flat and horizontal before arching down to the margin ; there is an indication of a weak median ridge across the fascia which occupies the whole posterior and outer half of the pygidium which is gently arched down. The strongly convex axis, which is faintly ridged along the middle line, projects in front of the anterior margin of the pygidium and occupies here about one-third its width: a deep pit-like marginal notch defines it on each side, but the converging axial furrows are very shallow. The anterior lateral angles of the pygidium are strongly truncated at an angle of about 120°. The present author has described a somewhat similar pygidium from the Ordovician of Yunnan as *I.* aff. *schmidti* (1917 (2), p. 46, pl. vii, fig. 12). Our present Balclatchie specimen has a pygidium with a less parabolic shape than the typical *I. schmidti*, and the more elevated and prominent axis is also a distinctive feature. Another allied species is *I. liluensis* Reed from the Northern Shan States (1915, p. 37, pl. vii, figs. 4–7) which has a similarly well-defined triangular pygidial axis, and *I. spitiensis* Reed from the central Himalayas (1912, p. 95, pl. xiv, figs. 4–14) may also be compared, both of which were observed to be related to *I. schmidti*. It may be remarked that *I. spitiensis* shows traces of narrow rings on the axis as in our specimen. Gortani figures *I. spitiensis* from the Ordovician of the Karakorum (1934, p. 88, t. xix, fig. 3), and the incipient annulation of the axis of the pygidium is distinctly shown. Apart from this feature some of the specimens referred by Holm (1886, p. 116, t. viii, figs. 4*b*, 6*a*, 13*a*) to varieties of *I. oblongatus* Angelin have the shape of the axis and of the pygidium much like that of our specimen.

Dimensions.—Length 4·75 mm.; width 6·50 mm.
Horizon.—Balclatchie Beds.
Locality.—Balclatchie.

Family Proetidae

Proetus scoticus sp. nov. Pl. V, fig. 3

Head-shield broadly semicircular. Glabella short, wider than long, about two-thirds the length of the head-shield, semi-elliptical in shape, with gently arched sides and rounded anterior end, slightly pinched in at the base behind the large triangular faintly defined basal lobes which occupy the outer third part of the base of the glabella; there are also traces of two pairs of short lateral furrows in front of the basal lobes. Pre-glabellar area narrow in front of glabella, widening on each side, gently convex, arched down on each side. Anterior border of head-shield thick, rounded, prominent, as wide as middle of pre-glabellar area but narrowing somewhat at sides; marginal furrow strong, deep. Neck-ring composed of pair of transverse subcuneate lateral lobes occupying on each side the outer third part of neck-ring and directed slightly forwards laterally, indenting base of glabella; middle third of neck-ring simple, annular, convex, slightly arched forwards. Facial sutures with anterior branches arising on margin of head-shield at right angles to it and wide apart, running backwards and strongly inwards towards glabella and sweeping round the long, narrow palpebral lobes which equal about half the length of the glabella; posterior branch of facial sutures short, cutting posterior margin at acute angle. Eyes large, subreniform, situated close to glabella. Surface of head-shield coarsely granulated in all parts. Free cheeks not preserved.

Dimensions.—Length of head-shield, 10·00 mm.; width of middle shield between anterior branches of facial sutures on front margin, 11·00 mm.; length of glabella, 6·50 mm.; basal width of glabella, 7·75 mm.

Horizon.—Mulloch Hill group.

Locality.—Craigens.

Remarks.—There is only one cranidium of this trilobite so far found, but it is nearly perfect, though the eye and palpebral lobe on the right side only are preserved. The surface of the glabella is somewhat worn, so that the lateral furrows and lobes are indistinct; and the posterior wing of the fixed cheeks is not well preserved. The granular ornamentation is, however, well seen. The species which most resembles this specimen is *Proetus princeps* Savage, as figured and described by Foerste (1919, p. 389, pl. xix, figs. 13 A, B) from the Upper Medinan of Ohio, but the shape of the glabella in that species is more pointed and longer, ours more resembling in that respect *Pr.* cf. *undulostriatus* (Hall) as figured by Foerste (1919, pl. xix, figs. 10 A, B) from the Trenton of Kentucky. The typical *Pr. girvanensis* Ether, Jr. and Nich. from the Drummuck group of Girvan (1880, p. 169, pl. xii, figs. 7, 10) is also allied, but our Craigens specimen is certainly distinct. *Pr. latifrons* (McCoy) which the author (1904, p. 76, pl. xi, figs. 4, 4*a*) described and figured from the Mulloch Hill and Saugh Hill Groups at Girvan has a more pointed and longer glabella and the anterior border of the head-shield is narrower and less swollen and the tripartite division of the neck-ring is different; there is also no coarse granulation of the surface of the head-shield. The specimen from the Saugh Hill Group which the author described and figured as *Proetus interjectus* (1935, p. 40, pl. iii, fig. 23) differs in the anterior branches of the facial suture, being subparallel instead of widely divergent anteriorly and in the neck-ring having only small nodular lateral lobes. *Pr. distans* Lindström (1885, p. 79, t. xv, fig. 21) though allied is still less like it. The unnamed imperfect head-shield from Craigens described by me (1904, p. 81, pl. xi, fig. 13) as *Proetus* sp. ind. is probably allied to this new species.

BRACHIOPODA

Family Plectambonitidae

Aegiria ? balclatchiensis (Reed). Pl. V, fig. 6

In 1917 the author described a brachiopod from the Balclatchie beds as *Plectambonites quinquecostata* (McCoy) var. nov. *balclatchiensis* (1917, p. 877, pl. xiv, figs. 4–9), basing his determination on the external characters, the interior of neither valve being known. There is one internal cast of a pedicle-valve now available from Balclatchie in Mr. J. L. Begg's collection which fortunately is well preserved and inclines us to place it in the genus *Aegiria* (Öpik, 1933, p. 55) in spite of the apparent presence of minute denticulations on the hinge-line which suggest the genera *Sampo* (Öpik, 1933, p. 35) and *Plectodonta* (Kozlowski, 1929, p. 112). Professor O. T. Jones (1928, p. 468) considered this Girvan variety to be distinct from McCoy's *Orthis quinquecostata* which he put in his new genus *Sowerbyella*, but he believed that some of the specimens from various localities ascribed to McCoy's species should be referred to his genus *Leptelloidea* to which *Leptaena scissa* Dav. (which Öpik puts in *Leangella*) and some other British species were regarded to belong. The muscle-scar in our specimen is very short and transverse as in *Leptelloidea derfelensis* Jones (1928, p. 479, pl. xxv, figs. 3–7), but the diductors diverge at a very obtuse angle and have in the fork between them a small median, subcircular deep scar, thus agreeing better with *A. norwegica* Öpik (1933, p. 55, pl. x, fig. 4). There are no vascular markings visible, as in the genus *Sampo*, but radial rows of small elongated pustules are present as pits in the cast between the primary radial lines on the surface of the shell which show through on the interior. Apart from the absence of vascular trunks *L. balclatchiensis* has an interior much like that of *Sampo öpiki* Whittington (1938, p. 255, pl. x, figs. 15–16, pl. xi, fig. 10, text-fig. 3) from the Caradocian of North Wales.

Dimensions.—Length 3·5 mm.; width 6·0 mm.
Horizon.—Balclatchie Beds.
Locality.—Balclatchie.

Family Strophomenidae

Ptychoglyptus virginiensis Willard, var. nov. *irregularis.* Pl. V, fig. 8

The second figured specimen of *Plectambonites subcorrugatella* (Reed, 1917, p. 886, pl. xv, fig. 34) from the Whitehouse Group of Shalloch Mill, a species which O. T. Jones (1928, p. 463, pl. xxiv, figs. 14, 15) referred to a special group of his genus *Sowerbyella*, appears to resemble in its ornamentation the present specimen from the Balclatchie Beds, and the original description of the species which the author gave nearly applies to it. But the type of that species (op. cit., fig. 33) differs considerably. Since that was published Willard (1928, p. 283, pl. 2, fig. 12) has established a new genus *Ptychoglyptus* for a somewhat similar brachiopod, with *Pt. virginiensis* Willard, from the Holston formation of Virginia, as the genotype, and we may with some assurance refer the present Girvan species to that genus and regard it as a variety of the American species. The corrugations in the interspaces are, however, less regularly transverse than in the American species, and are occasionally more of the nature of pits; there are 16–18 primary radial lines in our present specimen instead of 10–12 in the type of *Plect. subcorrugatella*, and it is also much more transverse in shape. *Pt. shanensis* Reed (1932, p. 195, pl. 3, fig. 15) from the Southern Shan States is an allied species. The Norwegian brachiopod from stage 4*b* in the Christiania region named by Holtedahl *Plectambonites trabeata* Lindström var. *acuminata* (1916, p. 79, pl. xiv, figs. 6, 7) appears to belong to the same group of species. Our present specimen also resembles in many respects *Pt. bellarugosus* Cooper (1930, p. 269, pl. i, fig. 5) from the Upper Ordovician of Percé, Quebec, but the transverse wrinkles seem to be more regular and less coarse than in our specimen, though Cooper states that they have no special alignment.

Dimensions.—Length 7·0 mm.; width (estimated) 19·0 mm.
Horizon.—Balclatchie Beds.
Locality.—Balclatchie.

Rafinesquina cf. *hadelandica* Holtedahl. Pl. V, fig. 9

A small, longitudinally semi-elliptical pedicle-valve of a species of *Rafinesquina* has a gently convex surface without geniculation, a straight hinge-line not quite the length of the valve, a low, small inconspicuous umbo and a narrow triangular hinge-area. The surface bears about 18 strong radial lines, mostly primaries, widely separated and equidistant, with 3 to 5 smaller closely placed radial lines in the interspaces, all crossed by very fine concentric closely placed striae. There are no concentric rugae. The short dental plates diverging at a little more than 90° bound a rounded, weakly impressed muscle-area about one-fourth the length of the valve. In shape, ribbing, and general characters this specimen most resembles *R. hadelandica* Holtedahl (1916, p. 24, pl. 1, fig. 14) from the Ordovician of the Christiania (= Oslo) district, a species which its author regards as resembling *R. alternata* Emm. in some respects.

Dimensions.—Length 6·0 mm. ; width 5·0 mm.

Horizon.—Balclatchie Beds.

Locality.—Balclatchie.

GASTEROPODA

Family Patellidae

Archinacella unica sp. nov. Pl. V, figs. 5, 5*a*

Shell subovate, narrowing somewhat anteriorly to a bluntly pointed front end, obliquely conical, capuliform, with high pointed excentral apex incurved forwards overhanging concave anterior slope and situated at about one-fourth length of shell ; post-apical surface strongly arched down to posterior end ; sides somewhat compressed and descending steeply to lateral margins. Surface of shell smooth.

Dimensions.—Length 13·0 mm. ; width 8·0 mm. ; height 6·5 mm.

Horizon.—Drummuck Group.

Locality.—South Threave, Ladyburn.

Remarks.—This new species of which there is only one example has a different outline and greater height than *A.* cf. *prendergasti* Reed (1940, p. 156, pl. viii, fig. 5) from South Threave, and seems somewhat like the Minnesotan species *A. valida* (Sardeson) Ulrich (1897, p. 832, pl. lxi, figs. 14, 15) and *A. deleta* (Sardeson) Ulrich (1897, p. 831, pl. lxi, figs. 16–20) ; but judging from Billing's description of his species from the Black River Limestone named *Metoptoma erato* (1865, p. 39), of which there was no figure, it most resembles that species, the unusual shape with a pointed anterior end being peculiar to both.

LAMELLIBRANCHIATA

Family Nuculidae

Nuculites seductus sp. nov. Pl. V, fig. 10

Shell transversely elongate, narrowing slightly posteriorly; valves moderately convex, most so anteriorly, with two slightly divergent angular narrow diagonal ridges running back from behind umbo on posterior slope to posterior end of ventral margin; umbo broad, low, situated at about one-third the length of the valve; post-umbonal dorsal margin straight, oblique, running back to sharply rounded posterior end of shell; anterior end of shell short, rather broadly rounded. Pre-umbonal hinge-line with 5–6 transverse teeth; post-umbonal hinge-line furnished for three-fourths its length with about 12 smaller transverse teeth increasing slightly in size posteriorly; anterior muscle-scar large, with anterior edge deeply sunk; very weak clavicular ridge behind it curving gently forward to base of anterior end of valve. Surface of valve with concentric growth-lines of unequal strength.

Dimensions.—Length 10·00 mm.; height at umbo 5·25 mm.

Horizon.—Saugh Hill Group.

Locality.—Newlands.

Remarks.—There is only one specimen of this shell consisting of the internal cast of a right valve. On account of the internal clavicular ridge we must place it in the genus *Nuculites* Conrad 1841 (= *Cucullella* McCoy 1851), and we may compare it with *N. corrugatus* Williams (1917, p. 32, pl. xi, figs. 10, 12, 18) from the Silurian of Maine, but the pair of angular post-umbonal ridges to the posterior end more resemble *Ctenodonta* (*Koenenia*) *migrans* Beushausen (1895, p. 92, t. viii, figs. 4–7) of the Rhenish Lower Devonian. Kobayashi (1934, pt. 8, pl. 351, pl. iv, fig. 20) has figured a shell from the Ordovician of South Chosen as *Nuculites ? suboblongatus*, which seems somewhat similar to ours.

Family Cyrtodontidae

Vanuxemia ? girvanensis sp. nov. Pl. V, fig. 4

Shell obliquely oval; valves very gibbous; umbones small, anterior, in contact, incurved, and curved slightly downwards; dorsal margin of valves with very narrow flattened flange; surface of valves with concentric growth-striae.

Dimensions.—Length (oblique) 6·0 mm.; height 4·0 mm.

Horizon.—Drummuck Group.

Locality.—South Threave, Ladyburn.

Remarks.—This small shell of which the two valves lie side by side, neither showing the hinge, appears to belong to the genus *Vanuxemia* Billings and to resemble *V. dixonensis* Meek and Worthen from the Trenton Limestone of America (Ulrich, 1894, p. 550, pl. xxxviii, figs. 1–5) and *V. odhneri* Isberg (1934, p. 282, t. 21, figs. 3 *a–c*) from the Leptaena Limestone of Sweden. Wheelton Hind (1910, p. 514, pl. v, figs. 31–3) described a species of this genus from Balclatchie and Craighead, as *V. distans* sp. nov., but it can hardly be considered to be identical with this Drummuck shell. Owing to our ignorance of its hinge-characters it is possible that it may belong to the genus *Cyrtodonta* rather than to *Vanuxemia*.

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EXPLANATION OF PLATE V

(All specimens are in the J. L. Begg collection, to which the numbers in brackets refer)

Fig. 1.—*Pliomerella serotina* gen. et sp. nov. × 2. (BG 9480) Balclatchie Beds, Dow Hill, Girvan.

Fig. 2.—Ditto. Impression of part of same head-shield. × 2. (BG 9481).

Fig. 3.—*Proetus scoticus* sp. nov. × 4. (BG 9483) Mulloch Hill Group, Craigens, near Girvan.

Fig. 4.—*Vanuxemia* ? *girvanensis* sp. nov. × 3½. (BG 9484) Drummuck Group, South Threave, Ladyburn, Girvan.

Fig. 5.—*Archinacella unica* sp. nov. side view. × 2. (BG 6742) Drummuck Group, South Threave, Ladyburn, Girvan.

Fig. 5*a*.—Ditto. Top view of same specimen. × 2.

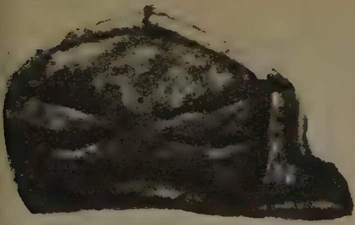
Fig. 6.—*Aegiria* ? *balclatchiensis* (Reed). × 10. (BG 9477) Balclatchie Beds, Balclatchie.

Fig. 7.—*Illaenus oblongatus* (Ang.) var. nov. *exstans*. × 6. (BG 9478) Balclatchie Beds, Balclatchie.

Fig. 8.—*Ptychoglyptus virginiensis Willard* var. nov. *irregularis*. × 4. (BG 9482) Balclatchie Beds, Balclatchie.

Fig. 9.—*Rafinesquina* cf. *hadelandica* Holtedahl. × 6½. (BG 9479) Balclatchie Beds, Balclatchie.

Fig. 10.—*Nuculites seductus* sp. nov. × 6. (BG 9485) Saugh Hill Group, Newlands.



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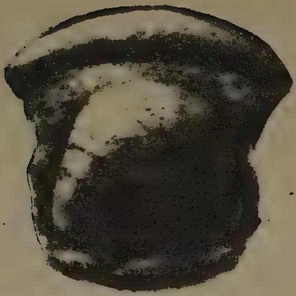

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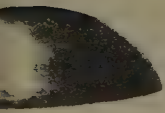

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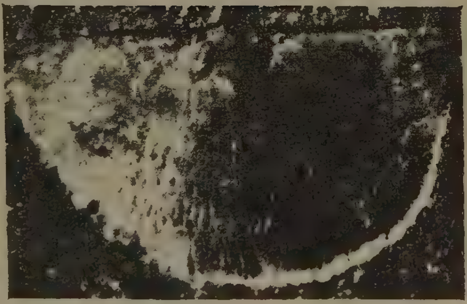

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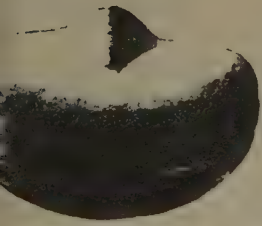

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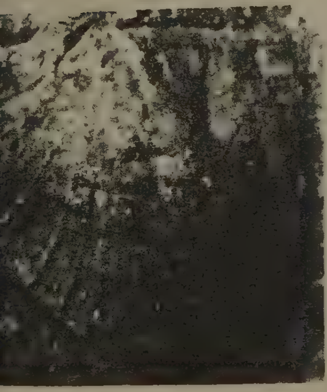

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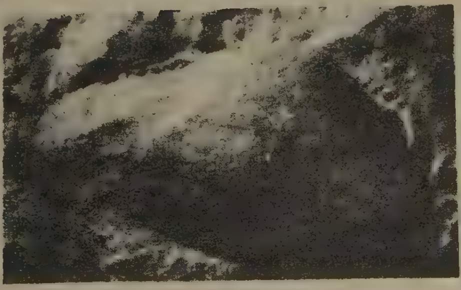

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[J. L. B. del., A. F. photo.

The Presence of the Namurian in the Bristol District

By L. R. Moore

(PLATE VI)

THE occurrence of massive reddish sandstones and quartzites lying between the Coal Measures and Carboniferous Limestone in the Bristol District has long been known. From their position and distinctive lithology, these beds have been referred to as the Millstone Grit by many early writers, amongst whom Austin (1865) may be mentioned. However, it has been shown that in part these beds are of Lower Carboniferous age. This was recognized by Vaughan (1905) notably in the Avon Section and at Long Ashton, where red grits and sandstones, previously regarded as Millstone Grit, were shown to represent horizon ϵ, and later found by him to be of D3 age. Dr. Stanley Smith (1930) has shown at Wick, on the eastern border of the Bristol Coalfield, that the lower part of the red and gritty beds of that area are likewise of Avonian D3 age. Dr. Smith suggested a non-sequence between Lower and Upper Carboniferous to occur some 30 feet above a thin gritty limestone, the " Mollusca Band " of D3 age. Between this horizon and that from which Yorkian plants were recorded (Crookall in Smith, 1930, p. 342), some 350 to 400 feet of grits and micaceous shales occurred. These beds were of uncertain age, and Dr. Smith held the opinion that part and probably most of these beds belong to the Upper Carboniferous.

Professor S. H. Reynolds (1930, p. 22) was of the opinion that since the rocks known as Millstone Grit in the Bristol Area were not comparable to the true Millstone Grit of the north of England, the term " Brandon Hill Grit " should be applied to them. However, Dr. Crookall (1935, p. 28) recorded *Neuropteris schlehani* in the higher parts of the " Millstone Grit " from Wick thus indicating an Upper Carboniferous age for some part of these beds, and it was suggested (Crookall and Welch, 1935, p. 26) that the terms *Farewell Rock* and *Brandon Hill Grit* be used for the Upper and Lower portions respectively.

Earlier work on the Coal Measures had suggested a gap of considerable magnitude between Lower and Upper Carboniferous, but it has been shown that the Coal Measures sequence includes strata representative of all the zones recognized in other areas (Moore and Trueman, 1937). The presence of the Lenisulcata zone within the Bristol District has been proved by Dr. Stubblefield (1932, p. 75), who examined the material collected by Bolton (1907) at Ashton Vale Colliery. It is clear, therefore, that strata equivalent in age to the upper part of the accepted Millstone Grit succession of the north of England, are present in the Bristol District.

The present paper deals with important evidence concerning the age of the lower beds of the Upper Carboniferous. It is shown that within the Bristol District the Namurian is represented, and it would appear that strata representative of the goniatite zone E are present. The use of the term Farewell Rock for these strata in the Bristol District would lead to confusion since they appear to be much older than the Farewell Rock of South Wales.

The evidence given below was obtained from a bore-hole within the City of Bristol. Boring, which was to augment existing water supplies, took place within the yard of the Bristol United Breweries at Rupert Street, Bridewell, Bristol. The site lies approximately one mile east of the Clifton Suspension Bridge on the southerly limb of the Westbury anticline. The position of the bore-hole is shown in Moore and Trueman, 1939, fig. 2.

By kind permission of the authorities, Professor Trueman and the writer were enabled to examine the core which had been carefully laid out in order of sequence, and indicated the beds to be dipping at a low angle of the order of 10 degrees.

The following section was observed :—

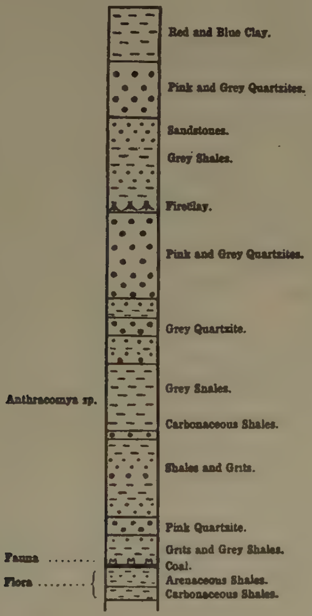
	Thickness in feet.
Red and blue clay	30
Pink and grey quartzites	29
Sandstones and grey shales with fireclay at the base	49
Hard pink and grey quartzites	45
Sandstone and grey shale	10
Hard grey quartzite	11
Sandstone and shale with pink quartzite at the base	15
Grey shales with black carbonaceous shale at the base yielding fragmentary plant remains	35
Pink quartzite	4
Arenaceous shale with thin grit bands and quartzite	42
Pink quartzite	8
Grits with grey shale bands forming the roof of a thin coal at 290 feet and yielding marine fossils	12
Grits and arenaceous shales with abundant plant remains	10
Soft carbonaceous shales with abundant plant remains (*Mesocalamites*) to 301 feet	1

With the exception of the last 12 feet of the core, the strata were unfossiliferous, a single poorly preserved non-marine lamellibranch referred to *Anthracomya* sp. was, however, recorded at a depth of 209 feet from a bed of grey shales.

The section is shown diagrammatically in Text-figure 1.

NOTES ON THE FAUNA

The marine fossils obtained from the roof of a thin coal at a depth of 290 feet are well preserved. They have been identified by Dr. Stubblefield who has kindly given the writer permission to include in this paper certain notes mainly relating to their identification.



TEXT-FIG. 1.—Section illustrating the sequence proved in the bore-hole, and showing the position of the fauna and flora. Scale 100 ft. = 1 in.

The fauna consists of one new species *Aviculopecten lepidus* sp. nov. herein described, *Limatulina ?* (*Palaeolima*) cf. *retifera* (Shumard), *Modiola* cf. *transversa* Hind, and *Lingula* cf. *mytiloides* J. Sowerby. These fossils are now in the collection of the Geological Survey Museum (Zh. 488–506).

Aviculopecten lepidus sp. nov. (Pl. VI, fig. 6.)

The material on which this species is founded consists of a well-preserved right valve and its impression, together with fragmentary remains of other valves considered to be the left valves of the species. (Geol. Survey Collection Nos. 7073 -9.)

Dimensions.—Presumably right valve, G.S.M. No. 70738; length of shell, 22 mm.; height of shell, 22 mm.; length of hinge line, 17 mm.; number of costae at margin of shell, 73; number of costae at middle of shell, 38.

Description.—*Right valve.*—Shell somewhat oblique, sub-orbicular in shape truncated by a straight hinge line, and possessing rounded anterior and lower margins; the posterior margin is nearly straight as far as the posterior auricle. The hinge line, though incomplete, would appear to be shorter than the maximum length of the shell. A well defined but small anterior auricle, triangular in shape, is set off from the main body of the shell by a prominent sulcus. The posterior auricle is larger and at least twice the length of the anterior auricle; its limits are not well defined since it is not separated from the body of the shell by any apparent fold or sulcus. This auricle forms, however, a prominent wing-like projection which in the specimen is incomplete. The lower border of this projection runs almost parallel to the hinge line and sharply recurves through a right-angle to meet the posterior border of the shell.

The umbone is poorly preserved, but appears to be flattened, slightly higher than the hinge line and placed far forward. The umbonal folds are weak, but appear to include an angle of some 80 degrees.

Ornamentation consists of numerous rounded costae which radiate from the umbones. Those on the posterior half of the shell retain a straight course even when approaching the region of the posterior auricle. On the other hand, costae of the anterior half of the shell show a distinct anterior bend which increases and is at a maximum in the region of the anterior auricle. Increase in the number of costae takes place by bifurcation, and very few intercalated costae are to be seen in the right valve. Portions of other valves show predominant intercalated costae and are considered to be the left valves of this species.

Growth lines are very fine and inconspicuous; they are best seen on the anterior auricle where they add the only ornamentation to this feature. On the posterior margin of the shell they are seen on the smooth portion of shell separating the wing-like projection of the posterior auricle from the main body of the shell. Here they swing in conformity with the shell outline, but are masked near the hinge line by three costae ornamenting the projection of the auricle, and running nearly parallel to the hinge line.

Distinction from Other Species

The present specimens most closely resemble the shells described and figured by Hind (1908, pl. i, figs. 11–13) as *Pterinopecten whitei* Meek. However, they differ from Hind's shells in that the posterior margin is more indented and the extension of the posterior auricle more elongate. There are further differences in the ornamentation ; the costae are more numerous, evenly developed, and less broadly rounded in the present species, whilst the growth lines are very weak.

Some of the shells of *Aviculopecten whitei* originally illustrated and described by Meek (1872), have been redescribed and refigured by Newell (1937) who selects Meek's species as the genotype of *Dunbarella* Newell. *Dunbarella whitei* Meek is a shell differing notably from Hind's in the unindented posterior margin. A characteristic of the species lies in the fact that the " rear shell margin meets the cardinal margin at about 120 degrees ". It would appear that the reference of Hind's specimens to *Dunbarella whitei* Meek is not justified.

The species here described shows some resemblance in general shape and ornamentation to *Dunbarella knightii* Newell (1937, pl. 2, figs. 8, 9, 10), but differs in its indented posterior margin and very much smaller umbonal angle. Unfortunately in the specimens here described the hinge area is not preserved to show any of the diagnostic characters considered by Newell in his revision of the Pectinacea. However, it would appear that the reference of the present specimens to *Aviculopecten* is in accord with Newell's revision of that genus, and that they represent a species not described by him.

Aviculopecten lepidus sp. nov. may be distinguished from *Aviculopecten gentilis* J. de C. Sowerby, which it somewhat resembles in general shape and ornamentation, since the latter species shows sub-central umbones and equally well-developed anterior and posterior auricles. Hind stated (1901, p. 86) that the right valve of Sowerby's species was smooth.

The shells described by Hind (1905, p. 128) as *Pterinopecten carbonarius* were unresolved by Newell in his revision of the genera, but they clearly differ from the present species in their unindented posterior margin and in the possession of a smaller number of broad raised costae separated by flattened spaces.

It is interesting to note that both *Aviculopecten gentilis* and *Pterinopecten carbonarius* were recorded by Bolton (1907, p. 445) from marine beds near the base of the Coal Measures in Bristol.

Limatulina ? (*Palaeolima*) cf. *retifera* (Shumard) (Pl. VI, fig. 5)

Dr. Stubblefield observed (*in litt.*) concerning these specimens :—

" Newell (1937, pp. 62–3) selects *L. radula* (de Koninck) as the genolectotype of *Limatulina* de Koninck, which would presumably make *Palaeolima* Hind a synonym of *Limatulina*. Hind (1908, pl. i, fig. 1) figured a shell which he named *Palaeolima retifera* Shumard, but as Fedotov (1932) pointed out, ' the American figures of this species differ widely.' The present shells differ somewhat from Hind's figure in being less oblique. The ornamentation is, however, similar. Examination of Bolton's Bristol Coal Measure material reveals close similarity between the present shells, and a specimen named by Hind as *Palaeolima retifera* Shumard. The prominent ears shown in Bolton's figure (1907, pl. 30, fig. 10) are not developed to such a degree on the actual specimen in Bolton's collection."

Modiola cf. *transversa* Hind (Pl. VI, figs. 7, 8)

These specimens are similar to Hind's (1908, pl. i, fig. 20), erroneously called *Modiola subelliptica* Meek, but are unlike Meek's original figure. They differ from Hind's specimens in being less oblique and possessing a larger and more rounded anterior end. Moreover, the straight hinge line meets the straight upper posterior margin of the shell sharply, and does not exhibit the gentle curvature shown in Hind's figure.

Hind (1894–1905, vol. ii, p. 67) described and figured the species *Modiola transversa* to which the present specimens appear to be related. There is close agreement in the shape and gibbosity of the anterior end and in the position and character of the umbones of the shell. The broad shallow constriction of the inferior border of Hind's species is not well seen on the present specimens. Further differences lie in the shape of the upper posterior shell margin which is rounded in Hind's species. The ornamentation of the present specimens is also less well marked.

The appearance of this fauna including species similar to those described by Hind (1908) as typical of his " Nebraskan Fauna " of the Millstone Grit of Scotland is important. Dr. Stubblefield observed, " I have not seen such a fauna in other Anglo-Welsh Millstone Grit, and in the absence of goniatites and the lack of species likely to be diagnostic the horizon represented is uncertain." However, by analogy with the Scottish molluscan fauna, Dr. Stubblefield suggested that it "probably represents the goniatite zone of E 2."

NOTES ON THE FLORA

Despite the fact that most of the plants occurred in arenaceous shale, they are extremely well-preserved and abundant, complete surfaces of a 9 in. diameter core in places being covered with plant remains.

A collection of plants included the following species :—

Neuropteris sp. nov. ?
Lyginopteris fragilis (Schloth.)
Diplotmema adiantoides (Schloth.)
Diplotmema adiantoides forme *silesiaca* Patt.
Sigillaria strivelensis Kidston
Sigillaria cf. *incerta* Kidston
Sigillaria spp.
Lepidophyllum lanceolatum L. and H.
Mesocalamites cf. *costiformis* (Stur)
Mesocalamites ramifer (Stur)
Asterophyllites equisetiformis (Schloth.)
Asterophyllites sp.

This collection represents the lowest floral horizon to be recorded from the Bristol District. I am indebted to Dr. Dix for assistance in its examination.

The forms referred to *Neuropteris* sp. nov. ? are, in the opinion of Dr. Dix, similar to the *Neuropteris* found in the Penwyllt beds at the base of the Millstone Grit of South Wales (Dix, 1933, p. 161), "and may possibly be a forerunner of *N. schlehani* or may represent a new species."

An unusual feature of the assemblage lies in the abundance of *Sigillaria*. Those forms included under *Sigillaria* spp. have been recognized by Dr. Dix as identical with forms from Penwyllt. The specimens of *Sigillaria strivelensis* and *S.* cf. *incerta* merit some attention since both species are very rare. These species were described and figured by Kidston (1916), and some of the specimens were obtained from the same locality, namely Stein's Fireclay Works, three-quarters of a mile north-east of Castlecary Railway Station, Stirlingshire, at a horizon within the upper part of the "Millstone Grit" of that area. It is interesting to note that it was from this locality that Hind (1908, p. 336) recorded some of the marine fossils to which reference has been made.

The present specimen of *Sigillaria strivelensis* exhibits the diagnostic characters of that species. It is similar to the specimen figured by Kidston (1916, pl i, fig. 5) which shows the interfoliar ornamentation to assume the form of a central band, a type of ornamentation more nearly akin to that of the present specimen. The collection contains three specimens of *Sigillaria* cf. *incerta* which agree closely with Kidston's figures (1916, pl. 2, figs. 5–7). It is clear that there is some variation within this species, and Kidston (p. 74) was doubtful whether *Sigillaria incerta* itself may not be an extreme variation of *S. elegans*.

At once the most interesting and most abundant members of the assemblage are *Lyginopteris fragilis* and *Diplotmema adiantoides*. Kidston (1923–24, p. 89) stated that *Lyginopteris fragilis* was not common, but where it occurs it is often plentiful. It has not been recorded in Scotland above the Upper Limestone Group. *Diplotmema adiantoides* (Kidston, 1923–24, p. 246) is common in the Upper Limestone Group and from the ranges of these plants it would appear that the horizon represented by the present flora cannot well be higher than the Orchard Limestone of the Upper Limestone Group. With reference to this horizon Macgregor and Pringle (1934, p. 6) stated that the Upper Limestone Group and part if not all of the Limestone Coal Group would fall within goniatite zone E.

The recognition of *D. adiantoides* forme *silesiaca* Patt., is interesting. The two species under discussion have proved to be of considerable zonal value on the Continent (Patteisky, 1935, p. 715), and their association is typical of the base of the Eumorphoceras zone. *Lyginopteris fragilis* does not appear above the Lower Ostrauer Beds of Silesia, and Walton (1931, p. 373), suggested that these beds and the underlying Hultschiner and Upper Wagstadter Beds should be correlated with the Upper Limestone Group of Scotland, a correlation which has been further demonstrated by Patteisky (1935, p. 732).

From a consideration of the flora, Dr. Dix concluded, "the horizon represented is slightly lower than that of the Penwyllt Flora of South Wales," which occurs within the lower part of the Basal Grits of the Millstone Grit Series. It has been suggested, by Dix (1935, p. 164) and later shown by Ware (1939, p. 201), that the plant assemblage of these beds is typical of the goniatite zone of Eumorphoceras.

It is clear that the present assemblage of plants is one common to the Eumorphoceras zone, thus indicating the presence of the Namurian within some part at least, of the Bristol District. This conclusion is strengthened by the evidence of the fauna which Dr. Stubblefield has suggested is "probably E 2".

The flora is therefore representative of a horizon below that of Kidston's "plant break", which occurs (Macgregor and Pringle, 1934, p. 6) "at or near the top of zone E". In Kidston's sense the collection shows "Lower Carboniferous" (i.e. below the "plant break") affinities, though the plants *S. strivelensis* and *S.* cf. *incerta* provide interesting exceptions as do the specimens referred to *Neuropteris* sp. nov.?, which may be the forerunners of *Neuropteris schlehani*.

It is pertinent to note that some of the specimens of *S. incerta* and *S. strivelensis* described by Kidston, were obtained by Tait during his investigation of the fauna of the lower part of the Scottish "Millstone Grit". Hind (p. 336) pointed out that specimens of the Nebraskan Fauna, though not found in situ had been obtained from above the Castlecary Limestone. Kidston considered the horizon from which the plants came to be within the upper part of the "Millstone Grit" and referred it to the Lanarkian Series.

The present discovery at Bristol of *Sigillaria* cf. *incerta* and *S. strivelensis* in association with typical "Lower Carboniferous" plants in Kidston's sense, constitutes therefore a further record of the same species of plants occurring both above and below the "plant break". It is to be noted that Kidston (p. 714) realized the similarity between *S. incerta* and *S. elegans*, and found some difficulty in separating the species. *S. incerta* may therefore be a forerunner of *S. elegans*.

From a consideration of the Scottish Carboniferous "plant break", Dr. Bailey (1926, p. 49) suggested that the sudden change of flora may be due to a replacement of the local flora by a southern competitor. However, comparison of the Penwyllt and Bristol Floras with that of Scotland from similar stratigraphical horizons below Kidston's "plant break", suggests that there was established a general similarity of flora in these regions. The identification and association of this flora with the goniatite zone E on the Continent, in South Wales and in Scotland, and the probability of its association with that zone at Bristol is noteworthy. This would appear to indicate that the southern flora was in essential respects similar to that of Scotland at a period just before the time of the supposed "plant break"; there is no evidence of the contemporaneous occurrence in these areas of a flora sufficiently distinctive to cause the sudden change of flora recorded at the "plant break" in Scotland.

Macgregor and Pringle (1934, p. 6) observed that the "plant break" was associated with an unconformity within the Scottish

Millstone Grit, which locally brought the Coal Measure Lamellibranch zone of *Carbonicola ovalis* almost directly on to Bisat's zone E. It may be pointed out that Weir and Leitch (1936) in their comprehensive study of the non-marine lamellibranch zones of the Coal Measures of Scotland found little positive evidence of the presence of the Lenisulcata zone.

There appears to be a lack of conclusive evidence in Scotland for the presence of goniatite zone H, indicating that the "plant break" there must be correlated with the evidence for marked unconformity within the Millstone Grit Series of Scotland.

Dr. Crookall (1939) has summed up the evidence concerning the "plant break" in Great Britain, and pointed out that Kidston urged its utilization in a revision of the classification. It would appear, however, that there is a scarcity of floral evidence from the critical zone of H, which might be expected in view of the predominantly marine nature of the sediments. The use of the term "Lower Carboniferous Flora", in Kidston's sense, has apparently caused confusion when applied to the lower horizons of the Namurian. It appears desirable to restrict the use of the term to floras occurring in Carboniferous rocks of pre-Namurian age.

General Discussion of the Bristol Namurian Sequence

The exact position of the present horizon within the Bristol sequence is unknown, but it is clear that it must lie some distance below any horizon seen by Bolton (1907) at the Ashton Vale Colliery. Bolton described a cross measures section extending to the "Millstone Grit" in which the Ashton Vale Marine Band was discovered. The upper limit of the Millstone Grit was placed some 150 feet below the main marine band in order to include within the Coal Measures a black shale bearing plant remains consisting of *Lepidophyllum majus*, *Sigillaria*, *Neuropteris*, and *Cordaites*. From this point the exploration branch entered hard massive grits, and alternating grits and mudstones to a total thickness of 130 feet before striking a water-bearing sandstone causing the workings to be flooded.

A line of survey was carried out from this point to the uppermost limit of the Carboniferous Limestone series in Ashton Park, which gave a thickness of 980 feet for the Millstone Grit between the limits above indicated.

The palaeontological evidence obtained from the Ashton Vale Marine Band was discussed (Moore and Trueman, 1937, p. 21) when it was pointed out that Dr. Stubblefield (1932, p. 75), had concluded that this marine band lay within the Lenisulcata zone. The goniatite fauna of this marine band (now in the Bristol Museum) was recently examined by Mr. W. S. Bisat and found to include: *Homoceratoides divaricatum* (Hind), *Gastrioceras coronatum* Foord and Crick, *G.* aff. *subcrenatum* (Schlotheim), and *Anthracoceras arcuatilobum* (Ludwig). A further fragmentary goniatite obtained from Ashton Vale tip and believed to come from this drivage was identified by Dr. Stubblefield as either *G. listerii* (Martin) or *G. coronatum.* This assemblage bears some resemblances to the goniatite faunas discovered by Ware (1939, p. 168) from near the base of the Farewell Rock of South Wales, and indicating a horizon within the goniatite zone of G.

The fact that some 1,000 feet of strata may exist between the limestone regarded by Vaughan as D 3 and the Ashton Vale Marine Band (a horizon in goniatite zone G) suggests that in this area the Namurian may be well developed. If the horizon of the flora and fauna considered here is correctly given as zone E, it appears that any stratigraphical break between the Lower and Upper Carboniferous must of necessity be small, and may even be non-existent.

The only exposure in the Bristol District where a succession from the Lower Carboniferous to the Upper Carboniferous may be studied, is that described in detail by Dr. Smith at Wick and previously referred to (p. 279). The occurrence of Avonian D 3 beds overlain by some 350 to 400 feet of grits and shales of unknown age, suggests that this sequence may again be fairly complete.

The strata referred to the " Millstone Grit " in other areas are noticeably thinner. Along the eastern border of the Bristol Coalfield a general thinning of the sequence is apparent. Some part of the grits at Yate are of Lower Carboniferous (D zone) age, but no palaeontological evidence of the true Namurian has been obtained. The Namurian if present here must be thinly represented.

In the Mendip area to the extreme south of the Coalfield, the strata included within the " Millstone Grit " are again thinly developed. Dr. Welch (1932) has identified Lower Carboniferous Beds of D 3 age in the eastern Mendips. The presence of goniatites from the Vobster Inlier (1931, p. 426) variously referred to *Gastrioceras cancellatum* (1931, p. 426), and *Gastrioceras crenulatum* (1932, p. 306) (1933, p. 41), was thought by Bisat (in 1931, p. 426) to indicate a lower G zone. It is possible that the Namurian if represented in the Mendip area is very thin. This is suggested by the presence of a thick bed of quartz conglomerate, the " Pebble Bed " described by Dr. Welch from Gilson's Quarry at Edford. In the absence of any fossil evidence above it, this bed was considered by Dr. Welch to be probably within higher beds of D 3. From lithological considerations, Dr. Welch considered the goniatite shales of Vobster to lie a short way to the north of the exposed beds in Gilson's Quarry. The writer has identified the " Pebble Bed " to the east near Harridge Wood, and here the upper bed of pink quartzite mentioned by Dr. Welch is seen to be overlain by dark grey micaceous shales. Similar shales slightly higher in the sequence, yielded poorly preserved shells referred to *Carbonicola* cf. *limax* Wright and *C.* cf. *obliqua* Wright. These indicate a horizon within the Lenisulcata zone and agree with Dr. Welch's suggestion that the goniatites came from a horizon not far above the beds exposed in Gilson's Quarry. If the " Pebble Bed " is taken as the base of the Upper Carboniferous, then some 350 feet of strata and probably less, lie between the Gastrioceras zone and the D 3 beds of the Lower Carboniferous. The thickness estimated from Bolton's records in the Bristol District between somewhat comparable horizons, namely the Ashton Vale Marine Band and the D 3 beds, would appear to be approximately 1,100 feet. From this evidence it would appear that the Namurian is represented within the Bristol District, but its presence has not been proved to the north or south where the succession is reduced in thickness.

In conclusion I would express my gratitude to Professor Trueman, who drew my attention to the core, and supplied data concerning it which he had observed, at the same time assisting in its breaking up. I am indebted to Dr. C. J. Stubblefield for examining the fauna and for the permission to publish those notes concerning it given above. Likewise I extend my thanks to Dr. E. Dix for her kindness in examining the flora, and to Dr. F. S. Wallis for permission to examine the Bolton Collection at the Bristol Museum and Art Gallery.

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EXPLANATION OF PLATE VI.

Fig. 1.—*Sigillaria strivelensis* Kidston. × 1.
Fig. 2.—*Lyginopteris fragilis* (Schlotheim). × 1.
Fig. 3.—*Diplotmema adiantoides* (Schlotheim). × 1.
Fig. 4.—*Sigillaria* cf. *incerta* Kidston. × 1.
Fig. 5.—*Limatulina* ? (*Palaeolima*) cf. *retifera* (Shumard). × $\frac{4}{3}$.
Fig. 6.—*Aviculopecten lepidus* sp. nov. (right valve). × 1.
Figs. 7, 8.—*Modiola* cf. *transversa* Hind. × 1.
Fig. 9.—*Lingula* cf. *mytiloides* J. Sowerby. × $\frac{4}{3}$.

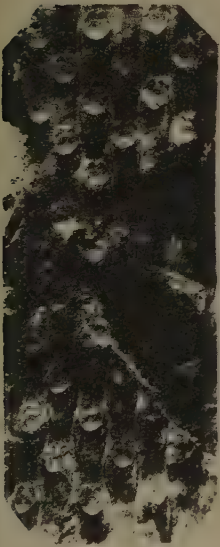


FIG. 1

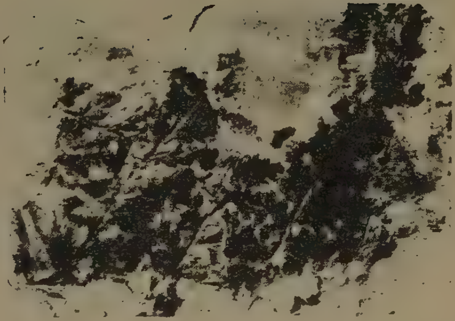


FIG 2

FIG. 3.

FIG 4

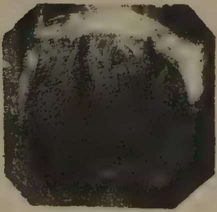


FIG 6

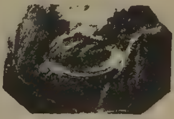


FIG. 8.

FIG. 5

FIG. 9.

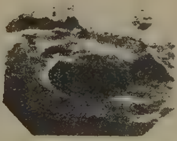


FIG. 7.

[*Photo. L. R. M.*

Namurian Fossils from Bristol District.

Allagecrinus biplex Wright—A Revision of the Species, with Notes on other Scottish *Allagecrinidae*

By JAMES WRIGHT

(PLATE VII)

INTRODUCTION

THIS paper is chiefly concerned with the micro-crinoid *Allagecrinus biplex*, recent discoveries of which have added considerably to our knowledge of the species. Others like *A. austinii*, *Callimorphocrinus scoticus*, and *C. elongatus* are only briefly noticed. Their adequate study and illustration must be deferred to more settled times.

In a former paper (Wright, 1933, p. 203), it was mentioned that while looking for adult specimens of *Allagecrinus austinii* in washed shale from No. 1 Bed, Invertiel, the coarser material only was examined, the finer residue being laid aside for future examination. This material, together with a quantity of shale collected later from Carlops, has now been carefully searched and has yielded 3,000 specimens of micro-crinoids all belonging to the *Allagecrinidae*. 2,000 of these are from Invertiel and 1,000 from Carlops. Details are as follows :—

NO. 1 BED

Invertiel

Allagecrinus austinii Carp. & Eth. young and immature specimens	11
„ *biplex* Wright	21
Callimorphocrinus scoticus (Wright)	1,797
„ *elongatus* (Wright)	167
Probably new genus	4
	2,000

Carlops

Allagecrinus austinii Carp. & Eth., young and immature specimens	27
„ *biplex* Wright	150
Callimorphocrinus scoticus (Wright)	823
	1,000

As was to be expected from previous experience, the Invertiel shale proved to be richer than that from Carlops, the number of specimens of all species collected from it working out at an average of 21¾ per hour. The lowest number obtained in one hour was 13 and the highest 38. From the Carlops shale the average worked out at 7⅓ per hour, lowest 1 and highest 15 per hour. It may be noted that these averages are much higher than those obtained in previous efforts in collecting these specimens (Wright, 1932, pp. 339–340), the figures then being 10 per hour for Invertiel and 2 per hour for Carlops. This is not due to any difference in the place of origin of the shale but probably to greater experience in "spotting" such small specimens.

Comparing the results as a whole, although the Carlops specimens are less numerous than those from Invertiel they are in a finer state of preservation. Young and immature examples of *Allagecrinus austinii* are, however, more often met with at Carlops as are also specimens of *A. biplex*. *Callimorphocrinus scoticus* is the commonest form at both localities. On the other hand, not a single specimen of *C. elongatus* has ever been found at Carlops. On this occasion 167 specimens of this species were found in the Invertiel shale.

Besides the species mentioned, four specimens belonging to an unidentified armless genus were found in the Invertiel shale (plate vii, fig. 4). The specimens are small and not well preserved. They resemble some others previously obtained at Invertiel, but as these are stored away and inaccessible at present it is considered better to leave over their study until all the material can be assembled again. This also applies to several other very small specimens, additional to the above totals. Some of these can be identified as young or larval forms of the flexible genus *Mespilocrinus*, others belong to inadunate forms. It is hoped to deal with them at some other time.

DESCRIPTION

Allagecrinidae Carpenter & Etheridge, emend. J. Wright 1933

Allagecrinus biplex Wright, emend.

Pl. VII, figs. 2, 3, 5, 6, 9, 12–14; text-figs. 1–10

Allagecrinus biplex J. Wright, 1932, p. 348, text-figs. 12–15, pl. xxiii, figs. 35–7.
Allagecrinus biplex J. Wright, 1933, p. 206, pl. xiv, figs. 13, 14.
Allagecrinus biplex J. Wright, 1939–1940, p. 50, pl. x, figs. 7 and 8.

A small species; cup with low basal circlet, sutures usually invisible; RR unequal in width, five to eight times higher than BB; LAR and RAR narrower than other RR; LAR supports one arm only, RAR usually one, exceptionally two arms; other RR have variable number of arms; right shoulder of RPR usually axillary and supports two up to five arms; total number of arms on all RR, plus an arm-like series of anal plates, five to nineteen or more; lowest plate of anal series rests in a V-shaped notch formed by the bevelling of left shoulder of RPR and a similar bevelling of right shoulder of LPR;

oral arch low ; anal opening into calyx at proximal end of posterior O ; plates rather thin, surfaces finely frosted or smooth ; column vermiform ; height of cup, exclusive of oral arch, up to 1·5 mm.

Syntypes.—J. W. Coll. Nos. A 35, plate vii, fig. 14, and A 35a (1939–1940, pl. x, figs. 7 and 8).

Paratypes.—J. W. Coll. Nos. A 36, text-figs. 1–2, 5 ; A 37 text-fig. 4, plate vii, fig. 5 ; A 38, text-fig. 6, plate vii, fig. 9 ; A 39, text-fig. 10, plate vii, fig. 12 ; A 40, text-fig. 8, plate vii, fig. 13 ; A 41, text-fig. 9, plate vii, fig. 2.

Localities.—No. 1 Bed, Invertiel, Fife ; Carlops, Peeblesshire.

Horizon.—Lower Limestone Group.

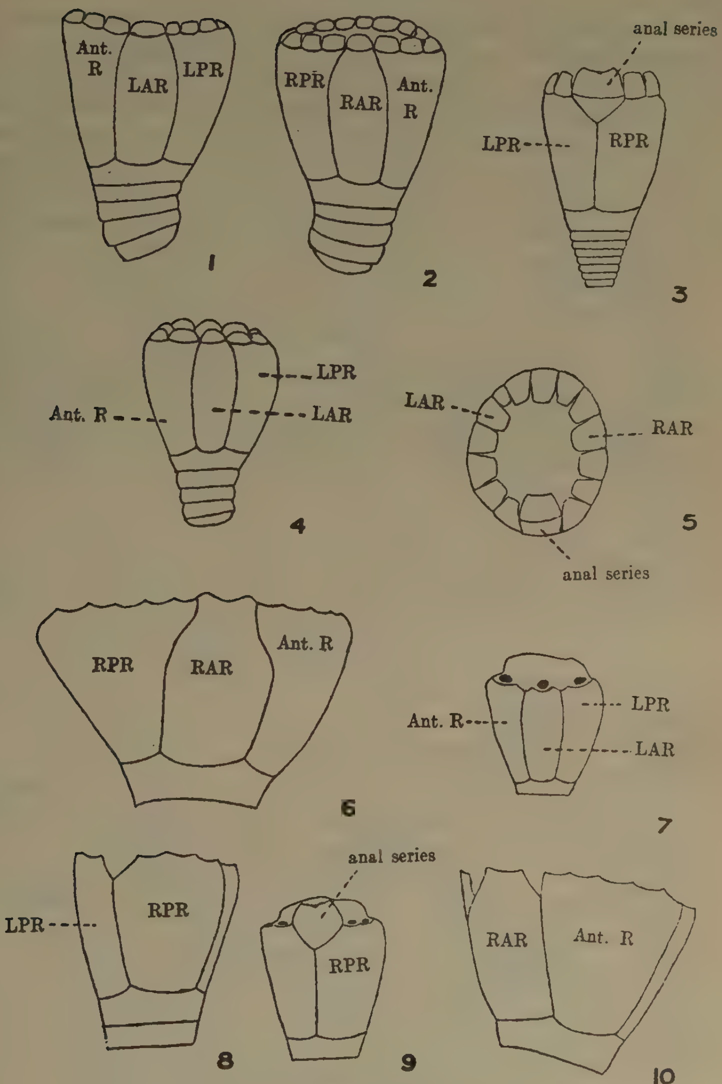
Remarks.—The original description of this species was based on twelve specimens, three from Invertiel and nine from Carlops (Wright, 1932, pp. 348–9). All were small specimens and one of the chief and distinguishing features then noted for the species was the presence of two arm-bearing facets on the right posterior radial. It thus differed from *Allagecrinus austinii* and *A. garpelensis*, both of which have only one arm-bearing facet on RPR. Among the 171 specimens now obtained, 152 have the RPR well preserved and this two-armed character holds good in over 66 per cent of the cups. There are others, however, most of which are larger and now recognized as more mature individuals of the species, where the RPR supported three, four, and in one case, five arms. In two very small specimens this plate has only one arm-bearing facet. We see, therefore, that while the two-armed character is the prevailing one in the majority of the specimens, it is variable in others. This somewhat enlarges our conception of the species and necessitates the present revision of the diagnosis.

As regards the radials in general, LAR and RAR are always narrower than the other RR. In the larger specimens, they may broaden out in their centres, but tend to narrow considerably at the top. Conversely, LPR, RPR, and Ant.R in these cases broaden out at the top (plate vii, fig. 9, text-figs. 1, 2, 4, and 6). The LAR in all specimens has only one arm-bearing facet. In six examples the RAR has two arm-bearing facets, but these appear to be exceptional, the prevailing number for this radial also being one. Generally, the arm-bearing facets on RPR, LPR, and Ant.R appear to increase with the size—or age—of the specimens, three or four being quite a common number on these plates in the larger examples. The plates of the cup are thin and apparently rather susceptible to pressure. This is specially noticeable in the larger examples, nearly all of which are flattened. Nineteen are so badly crushed that the radial facets cannot be counted.

Most of the smaller specimens, i.e. those up to about 1 mm. in height, are fairly round in shape, but some have the appearance of being compressed and are narrower from LAR to RAR. Others are narrower from posterior to anterior (plate vii, figs. 2, 3, 6, and 14, text-fig. 7). As a rule, such specimens have the oral arch in place, but this structure is missing in the larger individuals. Excluding the nineteen badly crushed examples noted above, it is quite easy to count the number of arm-bearing facets on the radials of the larger specimens, even if the cups are flattened, since the radial facets are usually uninjured (text-figs. 6 and 10). In some of the smaller examples, however, apart from RPR, LAR, and RAR, it is sometimes difficult to determine whether LPR and Ant.R supported more than one arm. The facet in the middle of the radial surface is always quite distinct and well defined, but the outer edges of the radial, on one or both sides of the facet, do not always fit closely in line with the oral arch. Although under the microscope no facets are discernible, it is just possible that some of these surfaces may have supported additional arms. Similar features are occasionally seen in immature specimens of *A. austinii*, where the top of the radial only projects slightly beyond the line of the orals. In these cases also no facet is clearly visible and were it not for other evidence it would be difficult to believe that such a radial supported an arm plate. That in some cases it did so is proved

EXPLANATION OF TEXT-FIGS. 1–10

TEXT-FIGS. 1–10.—*Allagecrinus biplex* Wright. Text-figs. 1 and 2, lateral views of a well-preserved mature specimen with part of the column attached and circle of primibrachs on the radials. Text-fig. 3, posterior view (diagrammatic) of a rather smaller specimen, showing the two lowest plates of the anal series. Text-fig. 5, top view of specimen shown on text-figs. 1 and 2; the number of arms here is fourteen plus anal series, RPR 3, LPR 4, Ant.R 5, LAR and RAR 1 each. Text-fig. 4, lateral view of a somewhat crushed small specimen with part of column and primibrachs attached. The number of arms here is nine plus anal series, RPR 2, LPR 2, Ant.R 3, LAR and RAR 1 each. Text-fig. 6, lateral view of the largest specimen, considerably crushed, LPR missing; number of arms probably nineteen, RPR 5, Ant.R 7, LAR and RAR 1 each. Text-fig. 7, lateral view of a small calyx showing outline of oral arch. Text-fig. 8, posterior view of calyx with proximal columnal attached, showing the notch formed by the sloping right shoulder of LPR and left shoulder of RPR for the reception of lowest plate of the anal series. Text-fig. 9, posterior view of a medium sized specimen with large anal plate in position. There may be two plates here as in the specimen shown on text-fig. 3, but no suture can be detected under the microscope. Text-fig. 10, anterior view of a large specimen, slightly crushed. All × 18 approx.



TEXT-FIGS. 1–10.

by the specimen shown on plate vii, fig. 7, and others like it, which have an exceedingly thin primibrach in place.

In the small specimens which have the oral arch in position, the anal opening is usually distinctly seen at the proximal end of posterior oral (plate vii, fig. 6). In some cases also there is what looks like a tubercle or hydropore situated well up towards the distal end of this plate. In very small specimens an anal plate is sometimes in position. It rests in the notch formed by the bevelling of the left shoulder of RPR and a similar bevelling of the right shoulder of LPR. In such small specimens there seems to be only one plate, since no suture line can be detected, the upper part of the plate bending over towards the oral arch; but in larger specimens the notch was occupied by the lowest of a series of arm-like anal plates, the number of which apparently

STATISTICS OF *ALLAGECRINUS BIPLEX* WRIGHT

CARLOPS

No. of Specimens.	*No. of arm facets on radials.*					*Total number of arms, plus anal Series.*	*Height of cup exclusive of oral arch.*
	RPR	LPR	LAR	ANT.R	RAR		
1	1	1	1	1	1	5	·9 mm.
11	2	1	1	1	1	6	1·0 mm.
34	2	2	1	1	1	7	,,
1	1	2	1	3	1	8	,,
8	2	2	1	2	1	8	,,
1	2	2	1	1	2	8	,,
24	2	2	1	3	1	9	,,
1	2	3	1	2	1	9	,,
6	2	3	1	3	1	10	,,
2	3	2	1	3	1	10	1·0 to 1·3 mm.
1	2	2	1	3	2	10	,,
2	2	3	1	3	2	11	,,
14	3	3	1	3	1	11	,,
5	3	3	1	4	1	12	,,
6	3	4	1	4	1	13	,,
2	3	3	1	5	1	13	,,
2	3	4	1	5	1	14	1·3 to 1·5 mm.
1	3	4	1	4	2	14	,,
3	4	4	1	4	1	14	,,
1	4	4	1	5	1	15	,,
1	3	4	1	5	2	15	,,
1	4	4	1	6	1	16	,,
1	5	?5	1	7	1	19	,,
1	3	3	1		1		
1	3			4	1		
1	2	2	1		1		
1	4			4	1		
17	too crushed to determine						
150							

ABRIDGED TOTALS

2 specimens have 1 arm-bearing facet on RPR
89 ,, ,, 2 ,, facets ,,
35 ,, ,, 3 ,, ,, ,,
6 ,, ,, 4 ,, ,, ,,
1 specimen has 5 ,, ,, ,,
17 indeterminable

150

increased with the age of the individual. Generally the lowest plate is triangular in shape, filling in the notch between LPR and RPR (text-figs. 3 and 8). In several specimens the suture dividing the first and second plate of the anal series is well seen (text-figs. 3 and 5). The second plate is somewhat rounded and quadrangular in form. It was succeeded by others as is shown by the upper joint surface and median groove. The number of plates comprising the anal series is not known since no specimen is sufficiently well preserved to show a complete series. One of the most interesting examples, however, is shown on text-figs. 1, 2, and 5. This specimen has four of the proximal columnals in position as well as the complete circle of primibrachs and the two lowest plates of the anal series. The number of arms borne by this specimen was fourteen, three on RPR, four on LPR, five on Ant.R and one each on LAR and RAR. The primibrachs are somewhat short plates, curving inwards

No. 1 Bed, Invertiel

No. of Specimens.	*No. of arm facets on radials.*					*Total number of arms, plus anal series.*	*Height of cup exclusive of oral arch.*
	RPR	LPR	LAR	ANT.R	RAR		
1 .	2	2	1	1	1	7	0·9 mm. to 1·4 mm.
3 .	2	2	1	2	1	8	
1 .	3	2	1	1	1	8	
6 .	2	2	1		1	9	
3 .	3	3	1	3	1	11	
2 .	3	3	1	4	1	12	
1 .	3	3	1	5	1	13	
2 .	4	4	1	4	1	14	
1 .		4	1	6			
1 .	indeterminable						
21							

Abridged Totals

10 specimens have 2 arm-bearing facets on RPR
7 ” ” 3 ” ” ”
2 ” ” 4 ” ” ”
2 doubtful
21

Combined Totals, Carlops and Invertiel

2 specimens have 1 arm-bearing facet on RPR
99 ” ” 2 ” facets ”
42 ” ” 3 ” ” ”
8 ” ” 4 ” ” ”
1 specimen has 5 ” ” ”
19 indeterminable
171

and rather crowded. The number succeeding these is unknown. The oral arch is missing. Another interesting specimen is shown on plate vii, fig. 5, and text-fig. 4. This is a much younger individual. Four of the proximal columnals are still adherent and the circle of primibrachs is also intact. The total number of arms borne by this specimen was nine, two on RPR, two on LPR, three on Ant.R and one each on LAR and RAR. The lowest anal plate is in position, but details are obscure since the cup is squeezed in the posterior region. The largest specimen of all is rather flattened (plate vii, fig. 9, text-fig. 6). The LPR is missing, but judging from the other specimens the number of arm-bearing facets on this plate was probably five. Since RPR has five arm-bearing facets, Ant.R seven, and LAR and RAR one each, the total number of arms borne by this individual must have been in the region of nineteen. The base and part of the radials of an even larger specimen were also obtained and it is possible that the number of arms for the species exceeded this total.

2. *Allagecrinus austinii* Carpenter & Etheridge

Pl. VII, figs. 1, 7, 10, 15

The number of specimens which can be referred without hesitation to this species is thirty-eight. Eleven are from Invertiel and twenty-seven from Carlops. As can be noted from the accompanying table they vary greatly in size and number of arm-bearing facets. They are all classed as immature for although half of the total specimens have five or more arm-bearing facets, i.e. one on each radial, some of the facets are not fully developed and all have more or less porous plates. None attain the average height of adult examples previously obtained. For the sake of comparison a list of the adult specimens found at Invertiel in 1933 is also given (Wright, 1933, p. 202). The height of the young and immature specimens is measured over the oral arch since this structure is usually in position. In the adult forms it is nearly always absent. The general appearance of the smallest specimen from Invertiel without any arms may be gathered from plate vii, fig. 1. This also is the appearance of the specimens with one arm-bearing radial when the calyx is viewed from the anterior, with RPR turned to the rear. In some of the small specimens, however, having one, two, or three arm-bearing radials, it is sometimes difficult, as in the case of *A. biplex*, to determine whether certain radials actually supported arm plates. When looked at from above one radial may bulge out rather more than another and may show a small gap or slit between the upper surface and the oral arch. A few specimens of this nature have a very thin primibrach in place. A specially well preserved and comparatively large one is shown on plate vii, fig. 7, where the radial in the centre of photograph—the Ant.R—is only slightly open at the top, but supports a very thin primibrach. In the table the number of arm-bearing radials refers to specimens in which the character of the arm-bearing facets is not in doubt. So far as the number of specimens allows us to judge the arm on RPR was always the first to be introduced and later this was followed by the development of LAR. In some cases the facet on this plate is very small compared with that on RPR. Then came RAR and LPR, the last to be formed being Ant.R. In general this evidence agrees with the conclusions

STATISTICS OF *ALLAGECRINUS AUSTINII* CARP. & ETH.

Young and Immature Specimens

No. of Specimens.	*No. of arm facets on radials.*					*Locality.*	*Total No. of Arms.*	*Height over arch.*
	RPR	LPR	LAR	ANT.R	RAR			
1	0	0	0	0	0	Invertiel	0	0·8 mm.
1	1	0	0	0	0	,,	1	1·0 mm.
4	1	0	0	0	0	Carlops	1	1·0 mm.
6	1	0	1	0	0	,,	2	1·1 to 1·3 mm.
2	1	0	1	0	1	,,	3	1·2 to 1·6 mm.
1	1	1	1	0	0	,,	3	1·0 mm.
2	1	1	1	0	1	Invertiel	4	1·3 to 1·6 mm.
2	1	1	1	0	1	Carlops	4	1·6 to 1·7 mm.
3	1	1	1	1	1	Invertiel	5	1·7 to 1·9 mm.
9	1	1	1	1	1	Carlops	5	1·4 to 2.0 mm.
1	1	2	1	1	1	Invertiel	6	1·5 mm.
1	1	2	1	1	1	Carlops	6	1·5 mm.
1	1	2	1	2	1	Invertiel	7	2·0 mm.
2	1	2	1	1	2	Carlops	7	1·5 mm.
1	1	3	1	3	1	,,	9	1·5 mm.
1	1	3	1	3	2	Invertiel	10	1·7 mm.
38								

Adult Specimens collected from Shale of No. 1 Bed, Invertiel in 1933

No. of Specimens.	*No. of arm-bearing facets on radials.*					*Total number of arms.*	*Height of cup only.*
	RPR	LPR	LAR	ANT.R	RAR		
9	1	1	1	1	1	5	2·5 mm. to 3 mm.
5	1	2	1	1	1	6	
24	1	2	1	1	2	7	
26	1	2	1	2	2	8	
13	1	2	1	3	2	9	
2	1	3	1	3	2	10	
79							

of R. E. Peck (Peck, 1935, p. 766) who made a study of the growth stages in *Allagecrinus americanus* Rowley and had a larger number of specimens to deal with. A tubercle or hydropore is always present on the posterior oral of the young and immature specimens and is useful in fixing the orientation, especially of the small one or two armed examples. The stage at which the anal opening appears in the calyx in these specimens has not yet been definitely fixed.

3. *Callimorphocrinus scoticus* (Wright)

Pl. VII, figs. 8, 11

This is the commonest species both at Carlops and Invertiel, 823 specimens having been obtained in the shale from the former locality and 1,797 from the latter. The specimens cannot be dealt with effectively at present and only a few notes are given. The specimens are of all sizes and range from very small armless individuals, less than 0·5 mm. in height to large robust adults measuring a little over 1·5 mm. in height. Among the adults, especially the well-preserved forms from Carlops, one notices many variations in the shape of the calyx. Perhaps the most abundant is the sub-globular shape already figured as typical of the species (Wright, 1932, pl. xxiii, figs. 13–17; 1939–1940, pl. x, fig. 6), but there are many others like that now shown on plate vii, fig. 8, which have a comparatively short and stout cup with very low basal circlet and rather more expanding radials. Some specimens of this shape have radials which bulge out considerably in their centres, the convexity contrasting greatly with the concavity of the sutural areas and giving these specimens a somewhat lobed aspect. Then there is the variety which I have called *contractus* (Wright, 1933, p. 203) in which the calyx is much narrower than the typical forms. At the extreme end of this series are a few forms like that shown on plate vii, fig. 11. Here the calyx is greatly elongated. The radials here also have a considerable bulge and the lobed aspect is pronounced. Given opportunity, one might sort out all the specimens according to shape, etc., and it would be interesting to note the number of each and how far they depart from the typical forms. Other than shape, however, there seems little to differentiate the adult specimens. All are of the usual five-armed character. The little knob or hydropore situated well up towards the distal end of posterior oral is visible in a side view, projecting as it usually does above the line of the oral arch. This is the general rule, but there is one feature, not hitherto noticed, which distinguishes some well-preserved specimens from Carlops, particularly the short lobed forms similar to that shown on plate vii, fig. 8, although it does not seem to be confined to them. Viewed from the side or from above, there can be seen a distinct swelling, rounded and like a flattened tubercle, which is situated about midway between proximal and distal ends of each oral and equidistant between the sutures of adjoining orals. In some specimens this swelling is more like a knob and when seen on the posterior oral is much larger than the hydropore. In others the swelling is enlarged and there is little space between it and the hydropore, the two almost coalescing. In one of these well-preserved specimens the hydropore has a distinct opening or perforation at its summit. Curiously enough, although the swellings may be noticed on all orals, including the posterior, in some specimens the posterior itself is free of them and the hydropore only is well shown. In other specimens the swellings have more the form of a ridge which extends from side to side on each oral across the concavity and connects the higher parts near the sutures. The purpose of the swellings and proportion of specimens showing them have not yet been worked out.

4. *Callimorphocrinus elongatus* (Wright)

167 specimens of this species were obtained in the shale from No. 1 Bed, Invertiel. As already noted, not a single specimen of this species has ever been found at Carlops. Little can be added to previous knowledge since these specimens have not been examined in detail. It may only be added that one or two of the present specimens are specially large for the species, the largest measuring 2 mm. in height over all.

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EXPLANATION OF PLATE VII

Some indulgence is asked for the plate which was prepared under difficulties and with improvised apparatus. Suture lines are reinforced with indian ink.

All specimens are from Carlops except Figs. 1 and 4 which are from No. 1 Bed, Invertiel. All figs. × 16 approx.

Fig. 1.—*Allagecrinus austinii* Carp. & Eth., young armless specimen.

Fig. 2.—*Allagecrinus biplex* Wright, posterior view, showing a single anal plate occupying the notch between LPR and RPR, and oral arch in position.

Fig. 3.—*Allagecrinus biplex* Wright, anterior view of a small specimen with oral arch in position.

Fig. 4.—Small specimen belonging to an unknown genus.

Fig. 5.—*Allagecrinus biplex* Wright, a small somewhat crushed specimen with columnals attached and primibrachs in position.

Fig. 6.—*Allagecrinus biplex* Wright, summit view of a small specimen showing the notch between LPR and RPR for the reception of anal plate. This specimen has two arm-bearing facets on RPR, two on LPR, and one each on the other RR.

Fig. 7.—*Allagecrinus austinii* Carp. & Eth., a comparatively large individual, showing Ant. R in centre of photograph with a very thin primibrach in place. The radial on the left, the RAR, has a normal primibrach in position. The radial on the right, the ~~RAR~~, has a well-developed facet but no primibrach attached. LAR

Fig. 8.—*Callimorphocrinus scoticus* (Wright), a well-preserved specimen of the short, stout, lobed variety, showing posterior aspect, left and right post. RR, with post. O in upper central part of photograph. The hydropore can be seen at the distal end of this plate and the swelling referred to in the text can be observed in front of the hydropore about midway from proximal to distal ends of the post. O.

Fig. 9.—*Allagecrinus biplex* Wright, a large flattened specimen, lateral view, with RPR to left, RAR in centre, and Ant.R on the right. This specimen had a total of probably nineteen arms.

Fig. 10.—*Allagecrinus austinii* Carp. & Eth., lateral view of fairly large immature specimen with strongly porous plates. RPR on left, RAR in centre, and Ant.R just showing on the right.

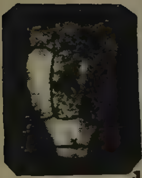
Fig. 11.—*Callimorphocrinus scoticus* (Wright), a greatly elongated and lobed variety, with relatively higher basal circlet and proximal columnal in position.

Fig. 12.—*Allagecrinus biplex* Wright, a fairly large slightly crushed specimen, RAR to left, Ant.R in centre, and LAR just showing on right. This specimen had a total of fifteen arms, four on RPR, four on LPR, five on Ant.R, and one each on LAR and RAR.

Fig. 13.—*Allagecrinus biplex* Wright, posterior view of a moderate sized cup, less crushed than usual, showing the V-shaped notch between LPR and RPR in which the lowest anal plate rested. Proximal columnal attached.

Fig. 14.—*Allagecrinus biplex* Wright, posterior view of one of the syntypes, A 35, RPR in centre, LPR on left, RAR on right. The two arm-bearing facets on top of RPR can be seen and on the left of these the notch for the anal plate between RPR and LPR.

Fig. 15.—*Allagecrinus austinii* Carp. & Eth., lateral view of a fairly large immature specimen. RPR is on the left and RAR in centre. Both have well-developed facets. Ant.R is on the right. The facet here is poorly developed and could only have supported a thin primibrach.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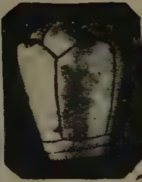
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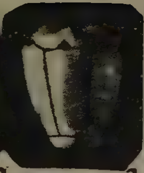
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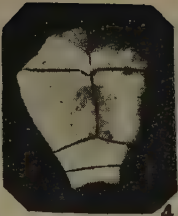
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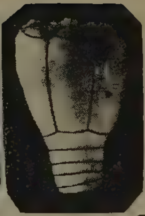
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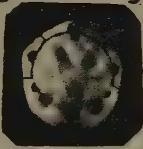
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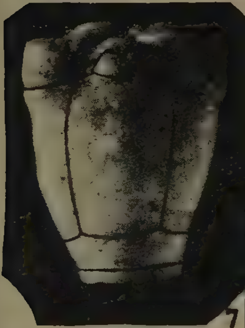
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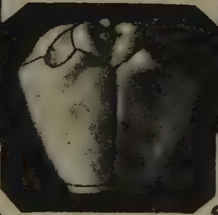
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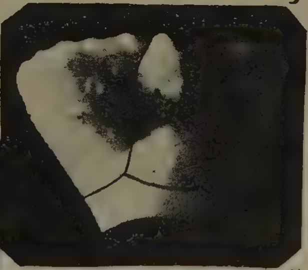
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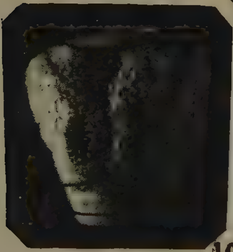
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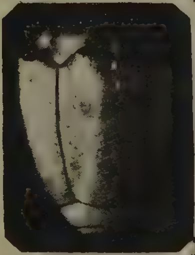
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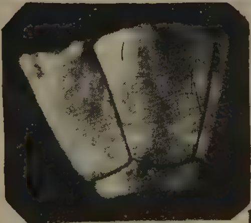
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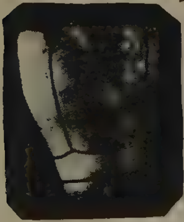
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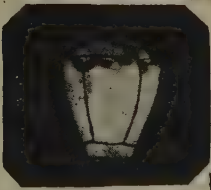
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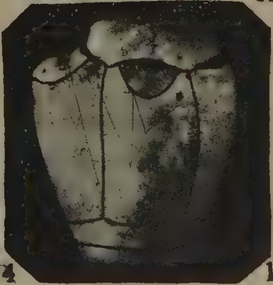
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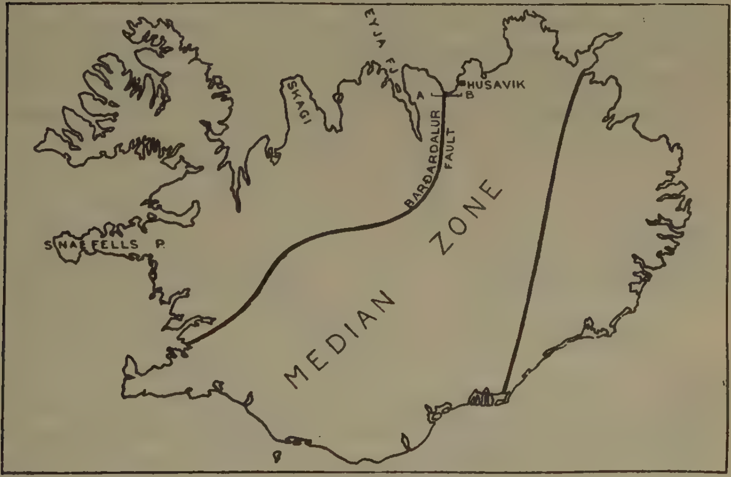
J. Wright Photo.

ALLAGECRINUS AND *CALLIMORPHOCRINUS*.

Icelandic Tectonics—Graben or Horst?

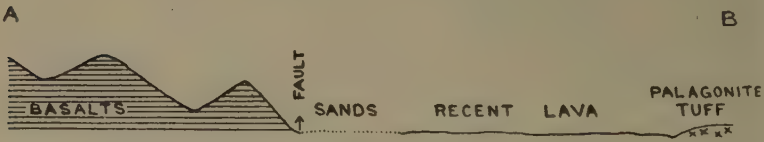
By L. Hawkes

THE younger rocks of Iceland (Pliocene to Present Day) occupy the broad median zone shown in Text-fig. 1; the boundaries are only approximate in places, and information is lacking with regard to the eastern one particularly. Outside this zone early Tertiary basalts predominate but (1) the uppermost basalts are regarded by some authors as Quaternary, (2) Quaternary and Recent volcanic rocks occur in the Snaefells Peninsula and in Skagi. The thickness of the early Tertiary series has been estimated at 3,000 m.; it may well be more, and it is reasonable to suppose that originally these basalts extended over the site of the median zone. Hitherto all workers in Icelandic geology have considered the zone to be a graben where the older rocks have been faulted or tilted downwards, but recently R. A. Sonder (1, 2) has put forward the startling idea that it is a horst, a view which is discussed, and not unfavourably, by H. G. Backlund (3). Before considering this new conception attention will be drawn to evidence in the neighbourhood of the north-western boundary of the zone, evidence which is not mentioned by Sonder and which, although it has been known for over 70 years, is often ignored or forgotten by writers on Icelandic tectonics.



TEXT-FIG. 1.

The relationship of the median zone to the western flanking region is shown in the section drawn across the Barðardalur fault at its northern end (Text-fig. 2). Six kilometres north of Husavik and at sea level, Pliocene shallow water sediments dipping 10°–15° N.W. lie unconformably on basalts which may reasonably be supposed to be of early Tertiary age, whilst at Forvaði Point, two kilometres north of Husavik, horizontally bedded Quaternary "Palagonite Tuff" rests unconformably on the same basalts, here dipping 35° N.W. West of the Barðardalur fault is a dissected basaltic plateau which rises to an elevation of 1,471 metres to the west of the Eyjafjord. Some consider the rocks of the plateau region to be wholly early Tertiary in age; others maintain that the uppermost basalts (no data have been given regarding their thickness, but 400 m. is probably an over estimate) are Quaternary. In either case the base of the Quaternary rocks is at a lower level east of the fault —at least 1,471 m. on the first view and *ca.* 1,000 m. on the second. Stratigraphically and topographically the median zone is here the downthrow side. Any horst conception would demand such a colossal amount of pre-Pliocene erosion producing a mysterious inversion of relief that it does not seem reasonable to entertain it. The problem of the date of the down-sinking is immaterial to the present discussion; it has been considered elsewhere (4), but advocates of the horst idea may well be asked to give their interpretation of the facts given above.



TEXT-FIG. 2.—Length of section 20 km. Vertical scale × 2.

On what grounds is the horst hypothesis advanced? It is suggested that many of the rocks of the median zone are older than the basaltic series flanking it—i.e. a horst relationship.

Apart from Recent volcanic rocks and glacial deposits the rocks of the median zone belong to the Palagonite Formation consisting of deposits of fragmental basic glass, often charged with basalt blocks—the Palagonite Tuff-Breccia, with inter-bedded moraines in places, and also many lava flows. The formation overlies early Tertiary basalts at Husavik and in the Snaefells Peninsula and is generally considered to be of

Quaternary age, but Sonder suggests that there are two Palagonite formations, one pre- and the other post-Tertiary basalts. The evidence cited in support of this is not impressive. Motoring over the Snaefells Peninsula " in bad weather and thick fog " Sonder (1, p. 433) observed in the mountain sides basalts above and palagonite tuff below. Thoroddsen thought that in such cases the tuff was banked against an upstanding block of Tertiary basalts, but Sonder thinks it more likely that the tuff underlies the basalts. This may well be so in some if not in all cases, but then the question of the age of the basalts becomes vital. Some of the basalts in the Snaefells Peninsula region, which were regarded by Thoroddsen as Tertiary, have been shown by H. Pjeturss to be Quaternary. G. G. Bardarson, a most reliable observer, worked in this area and he is quite definite that the Palagonite Tuff formation overlies the Tertiary basalts. He reported that in places the tuff formation is 7–800 m. thick, that it rests on marine deposits of early Glacial age, and moreover that within it are many basalts which in some localities predominate over the tuffs (5). One may strongly suspect that the basalts seen by Sonder to overlie tuffs were of Quaternary and not Tertiary age ; the base of the Tertiary basalts is not exposed in Iceland.

It is clear from a perusal of Sonder's writings that the horst idea derives from his conception of the mid-Atlantic ridge as a " langhorst " or embryonic upfold the axis of which is considered to continue through the median zone of Iceland. Another argument given is that whereas the bordering blocks of known graben are tilted outwards from them, in Iceland they appear, in part at any rate, to be tilted towards the downsunken area. These considerations, however, must take second place to the evidence cited above.

Recently the writer has had occasion to search the voluminous and scattered literature relating to the geology of Iceland and he has been impressed by the great amount of speculation and the common guessing at facts. So often the weakness of the factual basis is forgotten whereas the conclusions are passed on from one publication to another. The following quotation from a letter by Robert Dick, of Thurso, is not inappropriate here. Dissatisfied with the published accounts of the geology of Caithness, Dick wrote to Hugh Miller : " It is not by driving along the public roads, strolling along the sea shore, taking a distant view of Morven through a spy glass, that the depth of the Caithness schists is to be ascertained. . . . Geological maps and treatises are got up by men in red-hot haste. . . . The public are gulled, and the poor student, panting for knowledge, fills his belly with husks." Two illustrations will suffice.

A geologist sailing round the N.W. Peninsula of Iceland saw from the ship at a distance of at least 2 km. white sands on the shore. He concluded that they were quartz sands cast up by the waves from a crystalline basement which occurred in shallow depth, that here at last was the discovery of the basement of the Tertiary basalts of Iceland, etc. The publication of this and of subsequent comments has taken space in geological journals, the idea has got into general literature, and the investigation of the occurrence was one of the objects of an expedition from Scotland. Yet any tourist who had read a certain popular guide to the country would have known that these white sands were shell sands. The curious and perhaps incredulous reader may follow all this in the literature cited (6). To take another instance of a different character, S. Thorarinsson in his valuable study of the Dalvik earthquake of 1934 (7, p. 238) gives a map of the mountainous Eyjafjord region in which the coastal outlines and the sides of the main valleys are delimited by faults. Now if this interpretation is correct the region must be unique tectonically and no good "Physical Geology" could afford to be without a copy of the map. Yet, although the faults should be detectable in the many scores of sections provided in the stream courses which cross them, no evidence is given from any one of these sections. Until such evidence is forthcoming the cautious reader can hardly be blamed if he remains sceptical about the map.

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On the Boundary between the Upper and Lower Cretaceous

By L. F. Spath

THE Cretaceous System of England, according to A. J. Jukes-Browne[1] is "naturally divisible into two distinct and different series of strata", namely a lower series consisting chiefly of sands and clays, and an upper series, consisting mainly of chalk. The succession on the whole is easy to unravel, and was correctly described (even before the name Cretaceous had been thought of) by Webster in his Letters, written in 1811 and published in 1816 in Sir Henry Englefield's *Isle of Wight*; it is almost exactly the same as we recognize it to-day. Two slight changes have been made, but they have been considered by some to be changes for the worse. Firstly, the beds to which the name "Greensand" had originally been applied by Smith and Webster[2] are now called "Upper" Greensand, a term that has given rise to much confusion[3]; and, secondly, the "Ferruginous Sands" are now known as "Lower" Greensand, a name that was strongly condemned by workers like Fitton, Godwin-Austen, and Judd. It is on record[4] that even Jukes-Browne admitted that he had long been endeavouring to do away with the awkward and misleading terms "Upper" and "Lower" Greensand; but these names, though better not used without locality, have now become too familiar and are too useful for mapping to be abandoned entirely in favour of the more precise stage names Cenomanian, Albian, and Aptian.

While there has been little change in our views on the general succession, there were many minor differences of opinion concerning the nomenclature and grouping of the various local beds and they were not smoothed out by the introduction of such names as Vraconnian, Vectian, or Selbornian, not to mention other divisions (Middle Cretaceous, Subcretaceous, Arenaceous, etc.) which never found acceptance in this country. The correlation of the Cretaceous thus became very involved at the end of the last century and it is sufficient to glance at the correlation-table in a standard textbook (A. Geikie [1]) to see to what a state of confusion the beds between the Chalk and the Lower Greensand had been reduced. It may now seem incomprehensible, but the zone of *Belemnites minimus* was included in the Neocomian ; the Albian Red Chalk of Norfolk was paralleled with the Cenomanian zone of *Holaster subglobosus*, and placed considerably above the Warminster Greensand of *varians* (Lower Chalk) age ; the Blackdown Beds of Upper Gault age and the Albian zone of *Ammonites inflatus* were referred to the Cenomanian, and so forth. Alas ! for all the good palaeontological work that had been done on these beds.

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[1] Cretaceous Rocks of Britain: I. Gault and Upper Greensand of England. *Mem. Geol. Survey*, 1900, p. 2.

[2] See Judd: On the Use of the Term Neocomian. *Geol. Mag.*, vii, 1870, 220.

[3] Spath, On the Zones of the Cenomanian and the Uppermost Albian. *Proc. Geol. Assoc.*, xxxvii, 1926, 420.

[4] C. P. Chatwin, The Geology of the Selborne District. *Trans. S. E. Union Sci. Soc.*, 1938 (*S. E. Natur. and Antiq.*, xliii), 53.

Everybody is now agreed that the Chalk is Upper Cretaceous and that the Lower Greensand should be grouped with the Lower Cretaceous ; but there is still a difference of opinion as to where the boundary line is to be drawn among the tangle of strata just mentioned. Now when Jukes-Browne [2] said that it was wrong to speak of Gault and Greensand as separate and independent formations, he had in mind the Upper Greensand, but he might almost equally well have been speaking of the Lower Greensand, or at least its upper beds (i.e. the Folkestone Sands). For recent work has shown that while Gault and Upper Greensand are largely, but not entirely, contemporaneous, the separation of the Gault from the Lower Greensand would mean a splitting up of the Albian stage. More inconvenient still, the inclusion of the Gault in the Upper Cretaceous would necessitate our drawing the line between the Upper and Lower Cretaceous not only through the middle of the Albian, but through the middle of the *mammillatum* zone, since this zone includes the basal Gault as well as part of the Folkestone Sands and the Carstone of the Isle of Wight. It was indeed proposed long ago by Mantell [3] and later by Topley and Jukes-Browne [4] to include even the Lower Greensand in the Upper Cretaceous and this could probably be defended on palaeontological or geological grounds quite as much as any other so-called natural subdivision ; but nobody adopted this classification.

Most geologists will probably agree that changes in our stratigraphical classification may become necessary. As H. B. Woodward [5] said, the steady progress of geological knowledge might lead us from time to time to make important alterations

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[1] *Text-Book of Geology*, 3rd ed., 1893, p. 938.

[2] Cretaceous Rocks of Britain. Vol. I : Gault and Upper Greensand of England. *Mem. Geol. Surv.*, 1900, p. 2.

[3] *The Geology of the S.E. of England*, 1833, p. 66.

[4] *Internat. Geol. Congress, Cambridge*, 1885. Reports of Sub-Committees on Classification and Nomenclature, p. 61.

[5] On Geological Boundary Lines. *Proc. Geol. Assoc.*, iv, 1875, 262.

. . . and new observations sometimes led to a different classification of old and recognized divisions. But the re-delimitation of stratigraphical units should not be subjective or arbitrary. Thus it seems to me desirable to inquire whether the two main divisions of the Cretaceous System can be established on an historical basis, that is, objectively, bearing in mind the gradual evolution of the meaning of Cretaceous. For I believe that, as Judd [1] held in 1870, and as advocated by later authors, priority should be respected in stratigraphical as much as in palaeontological nomenclature.

The term terrain crétacé was first used by J. J. d'Omalius d'Halloy [2] in a memoir written in 1813 and published in 1822, and it was quickly adopted not only by French authors, but, in its equivalent of Cretaceous, also by English geologists, notably Conybeare [3] in the same year (1822). But it should be borne in mind that the term Formation crétacé was meant for what had previously been described as Formation crayeuse,[4] that is the "Chalk Formation". It was a lithological rather than a chronological term as is obvious from the fact that Brongniart [5] promptly separated from the Cretaceous an Arenaceous System (for what we now call the Lower Cretaceous); and de Lapparent,[6] as recently as 1906, spoke of the Albian as the stage in which was initiated the substitution of detrital sediments by chalky deposits and which therefore marked the end of the Lower Cretaceous. Conybeare in 1822 and Ure [7] in 1829, when speaking of "upper cretaceous beds", thus also referred to the chalky texture rather than to the age in the modern sense; but in any case, Conybeare included his "Chalk Marl" (i.e. the Gault of Folkestone) in the lower division. It is true that later in 1822 Mantell,[8] who quoted Conybeare and Phillips, moved up the Gault and Malm rock (or Upper Greensand) to the base of the Chalk Formation; but the tables given for instance by Fitton (1824),[9] Murchison (1826),[10] Martin

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[1] *Op. cit.*, 1870, p. 220.

[2] See in *Elements de Géologie*, II, 2nd ed., 1835 (302); 3rd ed., (1838) 166.

[3] In Conybeare and Phillips, *Outlines of the Geology of England and Wales*, pt. 1, p. 120 (see also p. 109).

[4] J. F. d'Aubuisson de Voisins, *Traité de Géognosie*, ii, 1819, 367.

[5] *Tableau des Terrains*, 1829, p. 213.

[6] *Traité de Géologie*, 5th ed., 1906, iii, 1295.

[7] *A New System of Geology*, London, 1829, p. 278.

[8] *Fossils of the South Downs*, 1822, p. 22.

[9] Inquiries respecting the Geological Relations of the Beds between the Chalk and the Purbeck Limestone in the S.E. of England. *Ann. Phil.*, N.S. viii, 1824, table to p. 368.

[10] Geological Sketch of the North-western Extremity of Sussex and the adjoining parts of Hants and Surrey. *Trans. Geol. Soc.* (**2**), ii, 1826, 106.

(1828),[1] and especially by Phillips[2] and Lyell (1838),[3] all agree in putting the Upper Greensand and Gault below the Chalk Formation, i.e. with the lower division. De la Beche[4] made it equally clear that the upper portion of the Cretaceous Group was the "Chalk Formation"; and the original classification of Smith and Webster, Buckland[5] and Conybeare, as emended by Fitton,[6] is unambiguously shown in the following scheme, published in Ansted's[7] textbook of 1844:—

Cretaceous Group	II. Chalk Formation.	
	I. Green-sand Formation	3. Upper green-sand. 2. Gault. 1. Lower green-sand (Neocomien).

The concensus of opinion about the middle of last century was clearly in favour of restricting the Upper Cretaceous to the "Chalk Formation", as understood for example by Sharpe who undertook the description of its mollusca. Mantell's classification was probably not adopted, because, as already mentioned, in 1833 he included the Lower Greensand in the Chalk Formation and, contrary to everybody else, continued to consider the Chalk Formation and the Cretaceous system to be synonymous terms.[8] All these early authors, however, cared little about strict chronological divisions and J. Phillips,[9] as late as 1855 was still content to use the old names Chalk and Greensand Formations instead of Upper and Lower Cretaceous.

In 1851, however, Lyell[10] transferred the Gault to the base of his Upper Cretaceous Series. It is this change of view by Lyell, subsequently adopted also by the Survey (under De la Beche), which was responsible for the gradual[11] disappearance of the original classification, but the lack of agreement among workers on the Lower Cretaceous did not pass unnoticed, for Jukes[1] wrote in 1862: "Perhaps the best way would be to interpolate another distinct period between those called Oolitic and Cretaceous and to include in it the Purbeck, the Wealden and the Lower Greensand deposits; but this has not yet been attempted and it might possibly be attended with *as many difficulties as the present classification.*" Let it moreover be noted that as late as 1872 Page[2] stated that for the sake of the learner he had followed the USUAL grouping (into Chalk and Greensand Formations) though he also gave a table of the NEW arrangement "now adopted by Sir Charles Lyell and some other geologists".

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[1] *A Geological Memoir on a Part of Western Sussex*, etc., London, 1828, pl. i, fig. 2.

[2] *Treatise on Geology*, 1838, p. 153.

[3] *Elements of Geology*, 1838, p. 314; 2nd ed. (1841), p. 386.

[4] *A Geological Manual*, 1831, p. 254.

[5] In Phillips, *Outline of the Geology of England and Wales*. London, 1818 (folio-sheet appendix).

[6] Observations on some of the Strata between the Chalk and the Oxford Oolite in the S.E. of England. *Trans. Geol. Soc.* (2), iv, 1836, 105.

[7] Ansted: *Geology*, ii, 1844, p. 448.

[8] *Geological Excursions round the Isle of Wight, etc.*, 1854, p. 128.

[9] *Manual of Geology*, 1855, p. 351.

[10] *Elements of Geology*, 3rd ed., 1851, p. 209.

[11] The original subdivision was maintained by many geologists, from Portlock (*Rudimentary Treatise on Geology*, 2nd ed. 1852, p. 152), and Ansted, Tennant, and Mitchell (*Geology, Mineralogy*, etc., 1855, p. 106), to Page (*Advanced Text-Book of Geology*, 5th ed., 1872, p. 306).

On the continent, those who divided the Cretaceous into only two sections (e.g. F. A. Römer, 1841,[3] Beudant, 1851,[4] and Naumann, 1854,[5]) persistently included the Gault in the lower. D'Halloy (1838) himself adopted a three-fold subdivision, and in this he was followed not only by such authors as d'Archiac and Leymerie, but by modern geologists like Haug, Fallot and Jacob. Haug,[6] for example, as recently as 1907, gave reasons, both palaeontological and geological, why a tripartite division was preferable, although he had to admit that a bipartite classification was in general use and that the Albian was usually included in the Lower Cretaceous. The border-line between the Upper and Lower Cretaceous, however, was moved up and down even by systematists like Mayer[7] and Renevier,[8] so that Kilian[9] again had to plead that it was necessary to include the Gault in the Lower Cretaceous "for historical reasons". In his view "the historical method in such nomenclatorial questions, even if artificial, was to be greatly preferred to the supposedly natural delimitation of systems or stages, based on alleged palaeontological affinity and real or apparent transgressions".

The question of the relation of the Gault to the other Cretaceous divisions, moreover, had already been settled by a decision of the International Geological Congress at Zürich, according to which "wherever only two divisions of the

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[1] *Students Manual of Geology*, new ed., 1862, 602. Jukes was apparently unaware of the existence of Brongniart's Arenaceous System.

[2] *Loc. cit.*, pp. 307–8.

[3] *Versteinerungen des norddeutschen Kreidegebirges*. ii, 1841, 126.

[4] *Géologie*, in *Cours élémentaire d'histoire naturelle*, 5th ed., Paris, 1851, p. 232.

[5] *Lehrbuch der Geognosie*, ii, 1854, 915.

[6] *Traité de Géologie*, ii, fasc. 2, 1164.

[7] *Tableau synchronistique des terrains crétacés*. Zürich, 1872.

[8] *Chronographe géologique*, 2nd ed., 1896 (C.R., 6th Internat. Geol. Congress), 64.

[9] In Frech, *Lethaea geognostica*. II, Mesozoicum, 3, i, 1907, 2.

Cretaceous Series can be made, the Gault should go with the lower division ".[1] It is true that Topley and Jukes-Browne did not approve of this decision and once more suggested inclusion of even the Lower Greensand in the Upper Cretaceous; but no English geologist followed them in this suggestion. Jukes-Browne,[2] in fact, in a paper published in the same year, himself included the Lower Greensand again in the Lower Cretaceous.

In view of what has been stated above I suggest that the limit between the Lower and Upper Cretaceous can only be drawn at the base of the Chalk Formation. Jukes-Browne, when including the sands, marls, and clays of the Gault and Upper Greensand in the Upper rather than the Lower Cretaceous, acted contrary to his own definition of the Cretaceous System, quoted at the beginning of this article; he evidently just followed the practice of the Survey, as did Lamplugh[3] who, a quarter of a century later, unhesitatingly stated that it had " always " been the custom in England to include the Gault in the Upper Cretaceous. This assertion is hardly borne out by the facts recorded above.

I may add that I do not agree with Buckman[4] that the term Cretaceous is " strictly stratigraphical " and " unsuitable for chronology ". He suggested a new name (" Baculitoidic Period " as distinct from " Cretaceous System ") but in my opinion (and judging by the literature) the need for a duplication of nomenclature is no longer felt. It is generally clear from the context whether an author is referring to time or strata; and by adding period or system, and age or stage to the name used (Cretaceous, Albian) all ambiguity is avoided.[5] Most geologists would be bewildered by the expression " during the Pleurohoplitan, the last age of the Hoplital Epoch of the Lower Baculitoidic Period ". The phrase " at the end of the Lower Cretaceous period ", or more precisely " in late Albian times ", is not only simpler and more intelligible but even more appropriate than the expression " during the Pleurohoplitan "; for in many extra-European countries (some with a far more extended succession at the limit between the Upper and Lower Cretaceous than in England) the familiar Hoplitids and the genus *Pleurohoplites* in particular do not occur. " Names as such," of course, " are not so important as is the way in which they are used "[1]; and as the lithological term Cretaceous has come to mean something different and is now universally used for chronological purposes, so the geographical term Albian is no more " unsuitable " for chronology than for stratigraphy.

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[1] *Internat. Geol. Congr. Cambridge*, 1885, Reports of Sub-Committees on Classification and Nomenclature, 61.

[2] The Classification of Stratified Rocks. *Geol. Mag.*, 1885, p. 297.

[3] A Review of the Speeton Clays. *Proc. Yorks. Geol. Soc.*, xx, pt. i, 1924, 13.

[4] *Type Ammonites*, iv, 1922, 15.

[5] See Table of British Strata in *A Short Guide to the Museum of Practical Geology*, 3rd ed., 1922, p. 42.

CORRESPONDENCE

IMPRESSIONS OF BRACHIOPOD CASTS

Sir,—In the last November-December issue of the *Geological Magazine* you published an article by Dr. Sisson and myself dealing with phenol formaldehyde plastic employed as a casting material in the study of internal casts of brachiopods. The technique demands the loss of the fossil and, where the matrix is a porous sandstone, the vacuum treatment which has to be adopted may lead to overmuch penetration of the rock. More recently I have prepared impressions in a rubber latex (No. E10099, supplied at 7*s*. 6*d*. per half-pint by Messrs. T. Gerrard and Co., Ltd., 48 Pentonville Road, London, N. 1) which gives admirable results, particularly from sandstone casts. The material is painted on to the fossil and successive layers are applied, each layer first being allowed to dry, and after about six applications a thickness is obtained sufficient to prevent distortion by curling. The rubber compound is gently prised away, the original shape of the cavities of the cast being assumed. There is no distortion; shrinkage is slow and relatively small in amount. The method appears to be much the same as that described by Fischer (*Journ. Paleontology*, xiii, 1939, 621) in which a preparation of Airvulc Liquid Rubber produces a black impression. The latex mixture is creamy white in colour and Mr. Seavill and I have obtained good photographs either by using artificial light, a two and a half times filter and Eastman Panchromatic cut films, or by exposing Ilford Rapid Chromatic plates with daylight illumination without a filter.

Further impressions have been prepared in the phenol formaldehyde plastic from Upper Valentian mudstones and shales, the softness of which frequently precludes the use of any substance which has to be pulled away from the surface of the brachiopod cast.

Our procedure now is to make brachiopod impressions in the rubber latex when the specimens are preserved in sandstone or when types or single specimens alone are available, but for casts preserved in argillaceous sediments, particularly when these are soft, the phenol formaldehyde plastic is preferred because the impression is permanent and unshrinkable.

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[1] Chatwin, loc. cit., 1938, p. 53.

W. F. Whittard.

The University,
Bristol.
12th March, 1941.

THE UPPER OXFORD CLAY AT PURTON

Sir,—On page 170 of the May–June number of the *Magazine* the compositor has not quite accurately copied the correlation table. In the Warboys column the broken line representing the non-sequence should have been placed about an eighth of an inch higher, so as to include some of the Bukowskii Sub-zone. In the Woodham column, beds A, B should have been shown as almost as thick as the Scarburgense Sub-zone.

W. J. Arkell.

Boyne Court,
Boyndon Road,
Maidenhead.
9th June, 1941.

THE "DUNGHAN" LIMESTONE, AND RANIKOT BEDS IN BALUCHISTAN

Sir,—In my last letter (1941) I referred to collections recently made by the Burmah Oil Company on or near Dunghan Hill. The company have since sent these collections to me, and preliminary examination shows them to be of considerable stratigraphic interest.

One collection is from a section (29° 51′ : 68° 19′) on the Dunghan Range, where 1,215 feet of "Dunghan Limestone" had been judged to succeed Parh Limestones and intermediate beds of Cretaceous age. I found that the first 500 feet of this "Dunghan Limestone" is of Lower to Upper Maestrichtian age, having *Orbitoides media* d'Archiac in its earlier levels and *Omphalocyclus macropora* Lamarck in its later ones. The middle of the "Dunghan Limestone" contains at least 260 feet of Upper Ranikot beds, in which *Miscellanea miscella* abounds. Only the uppermost 230 feet or so of this "Dunghan Limestone" is of Laki age; *Alveolina globosa* Leymerie, *Alveolina ovoidea* d'Orbigny and *Sakesaria cotteri* Davies being its most notable contents. This fauna resembles that of the Sakesar Limestone of the Salt Range (Davies, 1937) more than the Laki of the Bolan region (Nuttall, 1925).

The other collection is from a section (30° 9′ : 67° 59½′) in the Mehrab Tangi near Harnai. Some 1,300 feet of "Dunghan Limestone" had there been judged to succeed the Parh Limestones. I found that the lower and upper elements of the Dunghan Range section seem here to be cut out; but the central element, or Upper Ranikot, expands to a great thickness of limestone whose fauna increases in richness from below upwards until, some 1,200 feet above the base of the series, it presents such a typical Upper Ranikot assemblage as *Nummulites nuttalli* Davies, *Nummulites thalicus* Davies, *Miscellanea stampi* (Davies), *Miscellanea miscella* (d'Arch. and Haime), *Operculinoides sindensis* (Davies), *Lockhartia haimei* (Davies), etc. This seems to correlate with the upper levels of the Khairabad Limestone of the Salt Range, and I suggest that this Baluchistan equivalent of the latter be called the "Harnai Limestone". The topmost 30-ft. limestone of this section shows a rather abrupt change in fauna, but contains numerous *Discocyclina ranikotensis* Davies, so cannot be later than lowest Laki in age.

I am much indebted to the Burmah Oil Company for sending me these collections, with permission to publish my results. I hope to describe and figure the contents of the Harnai Limestone in some detail after further examination. One of its most interesting features is the appearance in it of a species of *Orbitolina*, a genus long supposed to be confined to the Cretaceous.

L. M. Davies.

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Nuttall, W. L. F., 1925. Stratigraphy of the Laki Series. *Quart. Journ. Geol. Soc. Lond.*, lxxxi, 417.

GLACIAL DRIFTS

Sir,—No great foresight was needed to see that before long there would be found in Scotland that evidence for a post-Glacial "tundra" condition already noted elsewhere in Britain and Northern Ireland (Carruthers and Anderson, W., 1941.) But the times are out of joint for such inquiries, and I am therefore all the more obliged to Dr. J. G. C. Anderson, whose paper (1940) reached me but a few days after our letter to *Nature* appeared, for so promptly supplying the desired proof. For that is what his most striking piece of information amounts to; these vertical wedges of till, narrowing downwards into subjacent sands, are of post-Glacial date. They are "frost-wedges" of the type so well known elsewhere: at the present time such things are forming in Baffin Land (Paterson, 1940), in Siberia, in Alaska, and doubtless many other places. Such an explanation has not occurred to Dr. Anderson, so that his evidence is all the stronger because it is given unwittingly. He envisages a waste of frozen sand with wide-gaping fissures open to the very bottom—a state of affairs unknown nowadays in any region, Arctic or temperate. Further, he believes that these fissures were subsequently filled by the "ground-moraine" of an advancing ice-sheet, which—in utter contrast to the effect of such a thing on pre-Glacial sediments, whether consolidated or not—left the frozen sand undisturbed by forward movement of any kind. Finally, since other local till-on-sand contacts are equally unaffected (as indeed are countless others within my experience), he extends his hypothesis to them also.

That a great ice-sheet can move over sand without the faintest sign of disturbance is, of course, a cardinal "orthodox" axiom, for which mere superposition is held to be adequate proof. In one form or another (the "freezing" idea, or for that matter any other *raison-d'être*, is commonly omitted) it has been the basis of an endless stream of publications, and I cannot help feeling that it has had far too long a run. There is about it a *naïveté*, an unthinking acceptance of current dogma, which ill accords with a scientific outlook. Whether that be so or not, this very question of undisturbed till-on-sand contacts has received extended notice in "Northern Glacial Drifts", wherein ample reason was given in disproof of the orthodox view, and evidence led for an interpretation of a totally different kind. It is idle to dismiss that contribution, as Dr. Anderson does, with a mere footnote reference and the comment that the new ideas are "novel": rather should he consider, earnestly, the evidence which gave rise to those ideas. For the gage has been thrown and, unless the verdict is to go by default, the challenge must be met. I await the result with interest.

R. G. CARRUTHERS.

HIGH BARN,
STOCKSFIELD-ON-TYNE.

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CARRUTHERS, R. G., and ANDERSON, W., 1941. Letter to *Nature*, Jan. 4th, 1941, p. 28.

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REVIEW

GEOLOGY OF THE COUNTRY AROUND WAKEFIELD. *Mem. Geol. Surv. Gt. Britain, Expl. of Sheet 78.* By WILFRED EDWARDS, D. A. WRAY, and G. H. MITCHELL. H.M. Stationery Office, 1940. Price 5*s.*

"The great mass of information which has accumulated during the exploitation of the Coal Measures has been condensed and classified. Details especially of seam thickness are available in such profusion that generalization is essential and this has been effected mainly by the construction of isopachyte diagrams." This from the introduction to Chapter III, with an acknowledgment that condensation has been accomplished with little discard of essential information and that the isopachyte diagrams and numerous other maps are adequately reproduced, is sufficient reason why welcome to this Geological Survey Memoir by Wilfred Edwards, D. A. Wray, and G. H. Mitchell should be offered in the pages of this journal. It is a notable advance in presentation of Coal Measure stratigraphical evidence for academic study, and its records of lateral variation of coal beds, sandstone rocks and strata thicknesses will be appreciated and used by West Yorkshire mining engineers as they should be by geologists generally.

Other chapters of the Memoir are in standard form. Chapter V descriptive of the Yorkshire Coal Measures' palaeontology will be helpful for this and neighbouring areas. The non-marine lamellibranchs have been made full use of under the "stimulating guidance of Professor Trueman", and their local distribution is properly recorded. Goniatites have been secured from the Mansfield (Monk Bretton) Marine Band whose outcrop has been newly traced for several miles. The place of this and the "Shafton Marine Band" 500 ft. above it, and of a still higher, the "Wentbridge Top Marine Band" a further 100 ft. above that, have been recognized in shafts and exploratory borings further to the East.

Investigation of the Permian, Chapter VI, has revealed unexpected variability of some of its divisions with a general and considerable increase of thickness towards the East. It had not hitherto been understood that the Lower Magnesian Limestone of Yorkshire was deposited as an oolite with small or large masses of reef limestone intercalated at various levels especially above the basal fossiliferous beds. Over a considerable area near the Aire valley the Upper Magnesian Limestone is "virtually magnesia-free".

Chapter VIII on the present structure of the Coal Measures and Permian area is lucid and worthy of attention for transcription into textbooks. It is illustrated by 1 in. maps showing the contour of the Top Beeston and the Top Haigh Moor coal seams where these have been wrought almost to exhaustion from the major pits. These true pictures showing minor swells and hollows cracked and displaced in a net of conjugate normal faults complementary to the folding, do not at first sight suggest "a part of a shallow basin between . . . major anticlines at right angles", but this Wakefield country is in fact as little disturbed as any British coalfield and it is well to emphasize that in most coal field areas which are concealed and still undeveloped the geometry of the coal seams is to be expected more complicated than this.

Chapter IX describes the local drifts, making a distinction between patches of early boulder clay and gravel mostly on hill-tops, and spreads of later drift deposited in valleys or deltaic material associated with the glaciers of the Vale of York. The interpretations offered are suggestive, but for lack of evidence the story is incomplete.

During the war period 1914–18 and afterwards the coal field east of Wakefield was the locus of acute controversy concerning "splits" of coal seams and the origin of "wash-outs". With new facts gathered during the re-survey the evidence for channelling and for pene-contemporaneous deformation is re-assembled. No one explanation is completely satisfactory, and it would seem that something from both groups of protagonists is necessary for almost every case. The authors are to be congratulated on their clear and judicial statement of this evidence. The Wakefield sheet memoir is a good one and geologists and coal miners alike now look forward with added expectation for further interesting results from the re-survey of the adjoining Barnsley and Leeds sheets which, along with the Wakefield area, have been under revision for more than fifteen years.

W. G. F.

GEOLOGICAL MAGAZINE

VOL. LXXVIII. No. 5. SEPTEMBER–OCTOBER, 1941

The Geology of British Oilfields

3. The Oilfields of Burma

Compiled by P. EVANS, incorporating notes by C. A. SANSOM[1]

I. INTRODUCTION

THE oilfields of Burma lie almost entirely within the elongated Tertiary basin which runs approximately north-south and is bordered on the west by the Arakan Yoma and on the east by the ancient plateau of the Shan Hills. Most of the oil has been obtained from fields lying on a single line of folding and in a belt only 50 miles long between latitudes 20° 20′ and 21° 10′, the remainder being found in small fields situated at various places between latitudes 19° 25′ and 23° 45′.

The Arakan region on the west coast of Burma is in a different geographical and geological province and has been described by H. M. Sale and P. Evans in a recent number of the *Geological Magazine*.[2]

II. HISTORICAL REVIEW

The origin of the oil industry of Burma is not known. One legend is that a few centuries ago a warlike king of Burma, having raided the Arakan Coast, crossed the Yoma with his captives and rested at Yenangyaung on the way to his capital. To commemorate his exploits and acquire merit he built the Bayin pagoda and, after setting up a tablet to record this, left his prisoners as pagoda slaves in charge of the shrine The slaves became prosperous by collecting oil, eventually flung into the Irrawaddy the tablet recording their former despised position, and in due course established the right to win oil, thus becoming *Twinzayos* or hereditary oil-well owners. E. H. Pascoe refers to an unconfirmed record of a Chinese traveller who found oil being worked at Yenangyaung in the thirteenth century. Burma oil was known, although still rare, early in the eighteenth century, but by 1797 the industry was firmly established, with

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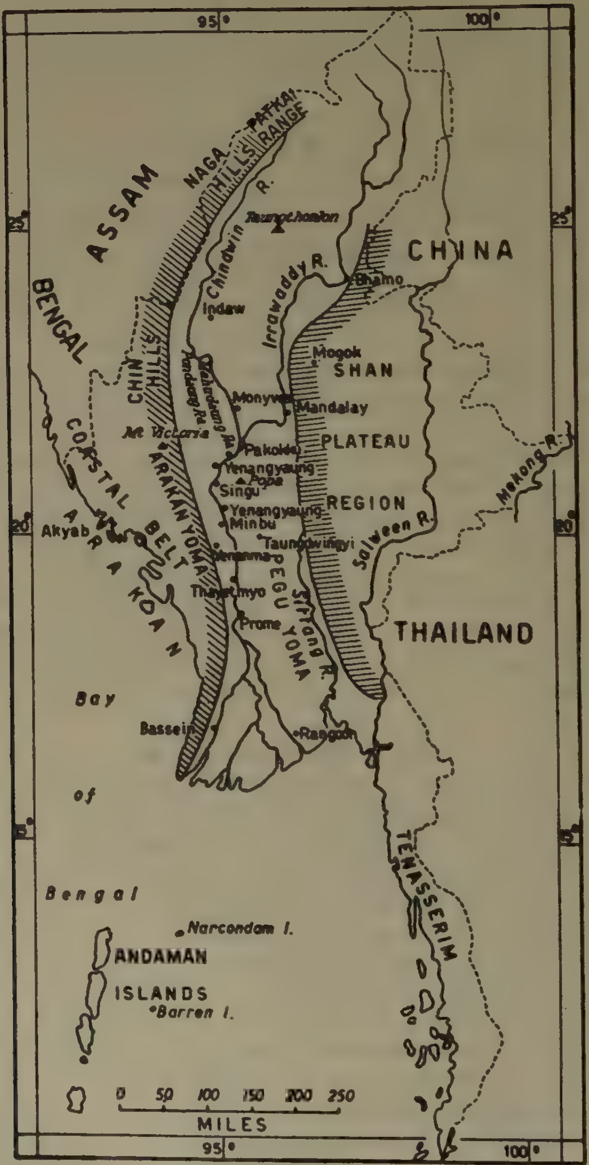
[1] Contributed by permission of the Burmah Oil Company, Limited.

[2] *Geol. Mag.*, lxxvii, 1940, 337–363.



Text-fig. 1.—Main Physical Divisions of Burma.

The edges of the high ground bounding the Central Belt of Burma are shown by shading.

several hundred hand-dug wells yielding altogether perhaps between 200 and 400 barrels per day, most of the production being sent down the river in earthen jars carried in large boats. In 1850 the wells seem to have been rather fewer, but even then a depth of 300 feet had been attained. It is probable that the earliest "wells" were mere pits dug on the sites of seepages; one may imagine that as their output declined the pits were deepened, until a depth of 30, 40, or 50 feet was reached. Proper timbering of the sides of the well would then be necessary and as this art became perfected the wells would be dug ever deeper and deeper. Hand-dug Burman wells were later started in other areas, for example, Yenangyat.

In the eighteen-seventies the Rangoon Oil Company was created to refine at Rangoon the production from the hand-dug wells; from this company there later arose the Burmah Oil Company, Limited (the parent of the existing company of that name), and this new company arranged leases or purchases of wells and sites from the *Twinzayos*, and applied for concessions of adjoining unproved territory. The Burmah Oil Company sent the first machinery for drilling wells to Yenangyaung in 1877 (Upper Burma having been annexed in the previous year) and to Yenangyat (45 miles to the north, on the right bank of the Irrawaddy) in 1893, and as a result the oil industry in these two fields developed rapidly. A simple and primitive form of cable drilling was the only type at first used, followed by more improved cable-tool methods. Although the rotary system of drilling was tried about 1912 it did not come into general use until about fifteen years ago, and cable-tool drilling is still employed for the shallower wells, for drilling into the oilsands after the casing has been cemented, and for deepening when the production from one sand has declined. In 1922 a scheme for the electrification of drilling and producing was inaugurated by the Burmah Oil Company at Yenangyaung and later extended to Singu—with important operational advantages and fuel economies.

The first geologist to visit the oilfields region was T. Oldham (the first Superintendent of the Geological Survey of India), who in 1855 accompanied a mission to the "Court of Ava". Oldham has been credited with being the first to recognize the connection between anticlinal structure and accumulation of oil, but his writing does not seem to bear this out. The first systematic geological examination of the region was carried out by F. Noetling in 1888 and the following years. In 1896 G. E. Grimes continued the work, and his mapping led to the proving of commercial production in the Singu field by the Burmah Oil Company. In the early years of the twentieth century the geologists of this company (then the only company developing the oilfields) began geological mapping in Central Burma with the object of finding other structures worth testing by the drill. The Geological Survey of India work in the oilfields region was resumed in 1905 and Pascoe's memoir, *The Oilfields of Burma*, was published in 1912. As geological staffs of the pioneering company and of later arrivals gradually increased, geologists became more and more concerned with development of the proved oilfields and less active in their search for new structures. In the years immediately after the 1914–18 war a more rapid increase in the geological staffs made specialization possible so that some geologists could concentrate on problems of oilfield development, others on exploratory work, and others again on palaeontology, sedimentary petrology, etc. The Burmah Oil Company has for many years maintained " Resident Geologists " at the main fields and gradually the location of new wells, drilling and casing policies, drilling and deepening programmes, estimations of reserves, regulation of gas/oil ratios, and (in short) the various tasks required for the scientific and most economical development of the fields have been taken over by the Company's geologists. The Government has always taken a keen interest in the efficient development of the oilfields and with this in view an Oilfields Commission was set up in 1908 ; following their report and recommendations a Warden of the Oilfields was appointed and an Advisory Board was created to deal with problems of development as they arose. In 1927 an earlier arrangement for a member of the Geological Survey of India to reside at Yenangyaung was revived.

Every effort has been, and continues to be, made to develop the Burma fields on the most scientific and up-to-date lines. All the most modern aids to both exploration and exploitation work are in use, and the geological staffs of the main companies are constantly on the look-out for improvements in technique which will lead either to the discovery of new fields or to the more efficient and thorough development of the existing ones. Amongst the recent technical advances that have been useful in Burma are the adoption of the Schlumberger system of logging the electrical conductivity of the strata (and so providing an excellent method of correlation between neighbouring wells), the introduction of drilling under pressure, which permits the successful penetration of high-pressure sands, and the use of chemically controlled drilling fluids.

III. OUTLINE OF THE GEOLOGY OF BURMA

(*a*) INTRODUCTION

Geologically Burma may be divided into four parts :—

(*a*) The Arakan coastal region bordering the Bay of Bengal, forming the westernmost strip ; it includes Cretaceous and Lower Tertiary rocks in the south and Upper Tertiaries in the north.

(*b*) The mountain range of the Arakan Yoma, Chin Hills, Naga Hills, and Patkai Bum lying to the east of the Arakan coastal belt.

(*c*) The Shan Plateau massif forming the easternmost part of the country.

(*d*) The main Tertiary basin lying between the Arakan Yoma on the west and the Shan Plateau on the east.

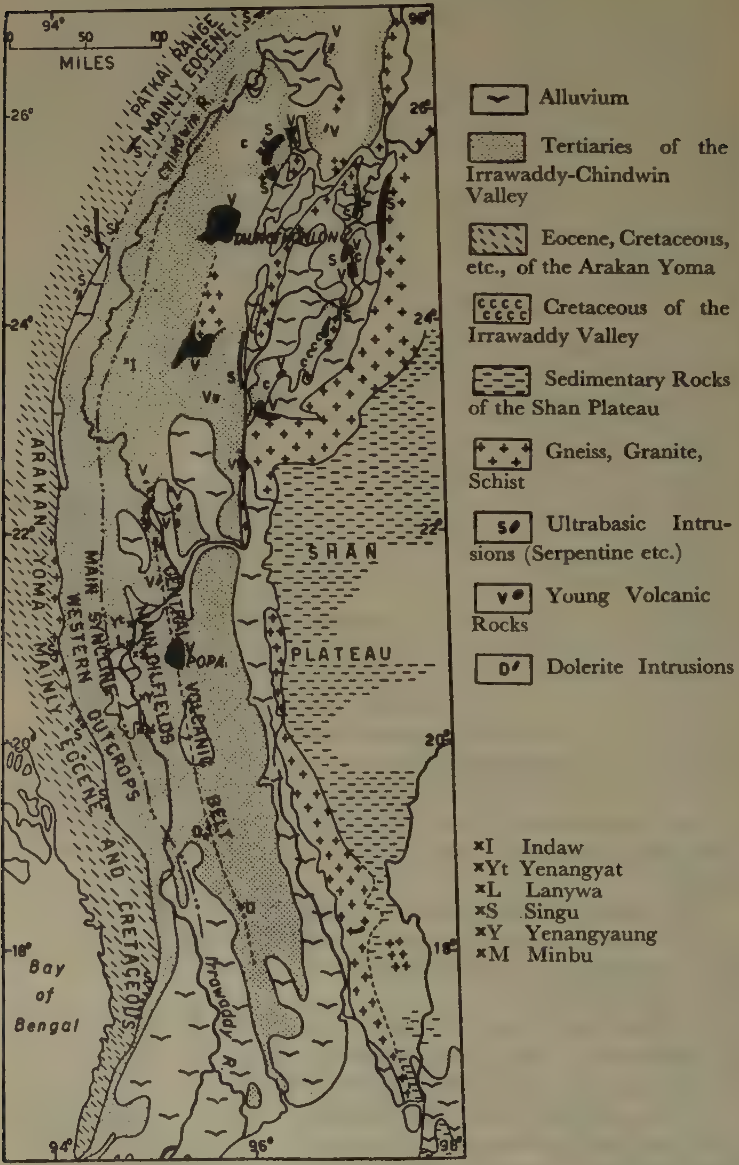
As mentioned above, the Arakan coastal region lying to the west of the Arakan Yoma has recently been described and will not be further dealt with here.

The Arakan Yoma mountain range is low in the south but gradually rises to levels of between 4,000 feet and 6,000 feet north of latitude 19°, attaining its highest point at latitude 21° in Mt. Victoria (over 10,000 feet). The hills are thickly forested with pines, teak, and bamboo, and the loftier points on and near Mt. Victoria are noted for the magnificent scarlet blooms of the giant rhododendrons (*R. arboreum*) which appear at the beginning of the hot weather (in March) and form an unforgettable spectacle. In the north the range continues as the Chin Hills and the eastern part of the Naga Hills, attaining a maximum elevation of over 12,000 feet in wild country inhabited mainly by primitive tribes, some of whom are still head-hunters. This part of the range forms the boundary between Burma and Assam.

The Arakan Yoma with its northern continuation through the Chin and Naga Hills is an interesting and complex area. The sedimentary rocks composing it are conveniently divided into four main groups :—

(*d*) The *Barail Series* of Upper Eocene age consisting mainly of sandstones ; this group probably forms the highest points of the northern part of the Assam-Burma dividing ranges.

(*c*) The *Negrais Series* of presumably Eocene age consisting of shales and interbedded sandstones ; this group is slightly metamorphosed and is probably equivalent to the *Disang Series* of the northern end of the range.



TEXT-FIG. 2.—SKETCH-MAP OF BURMA GEOLOGY.
Compiled mainly from maps of the Geological Survey of India.

(*b*) The *Ma-i Series*, believed to be Cretaceous and composed of shales with characteristic purple streaks and bands of light-coloured dense limestones ; the rocks show some metamorphism. The series is probably equivalent to the Akral Limestone of Manipur.

(*a*) The " *Axials* " (using this term in a restricted sense for rocks apparently older than the Negrais and Ma-i Series), a more highly metamorphosed group of quartzose schists and phyllites.

Igneous activity is widely manifest ; the main intrusions of serpentinized gabbros and peridotites occurred probably in late Cretaceous and Eocene times.

The age of the Arakan Yoma has for long been a subject of discussion. The metamorphosed rocks found near the eastern edge of the range opposite the oilfields region and in some other sections (e.g. near Mt. Victoria) are so much altered as to suggest a large gap between them and the Cretaceous. E. L. G. Clegg has recently shown that the Triassic fossils supposed to have come from the " Axials " were almost certainly found in another part of Burma, and several geologists have suggested that the oldest beds of the Arakan Yoma may be Pre-Cambrian ; on the other hand, where undoubted Negrais or Ma-i rocks are locally more highly metamorphosed than usual it is difficult to distinguish them from the apparently older schists and phyllites, and this has led to the suggestion that none of the Yoma rocks are older (or much older) than Cretaceous.

The Cretaceous Ma-i Series is well developed at the southern end of the Arakan Yoma, where it seems to be in close association with the Eocene shales ; both Cretaceous and Eocene show slight metamorphism. Farther north, towards the Patkai Range, the Eocene rocks in the interior of the range have been altered to slates, and near the border of Manipur and Burma R. D. Oldham found beds which are probably representatives of the Ma-i Series. In the Patkai Range (separating Upper Assam from Burma) most of the higher ground is formed by the Barail Series and the lower ground by the Disang Series. Along the eastern edge of the Arakan Yoma there are a number of sections showing unaltered Eocene rocks, usually with a basal conglomerate, resting unconformably on the " Axials ". The relationship between the unaltered Eocene rocks immediately east of the Yoma, the slightly altered Eocene and Cretaceous rocks within the Yoma, and the highly altered " Axials " presents problems which are not likely to be solved until the hills have been much more thoroughly examined.

To the east of the Tertiary basin lies the elevated Shan Plateau, which owes its chief features to the Plateau Limestone of Devonian to Permo-Carboniferous age, overlain by detrital beds of Jurassic and Cretaceous age. The Plateau Limestone rests unconformably on highly disturbed Lower Palaeozoic and Pre-Cambrian rocks. Granitic intrusions of presumably Mesozoic age are common, and the famous Ruby Mines of Mogok occur in the vicinity of such an intrusion. The plateau, which like the Arakan Yoma is richly forested, rises to heights of over 7,000 feet and has been noted for its abundant wild life.

(*b*) STRATIGRAPHY OF THE TERTIARY BASIN—WESTERN OUTCROPS

As G. W. Lepper remarks in his paper given at the World Petroleum Congress in 1933, "the great thickness of Tertiary rocks which occurs in the Chindwin-Irrawaddy basin is well exposed in stream sections along the eastern flank of the Arakan Yoma and Chin Hills. Here the whole sequence from Lowest Eocene to Upper Miocene, and possibly Pliocene, can be studied in a long eastward-dipping monocline. The lateral variation from north to south along the outcrops is also clearly revealed. . . . For some years past the Western Outcrops have been closely examined and rich collections of fossils have been made." The Tertiary succession in these Western Outcrops has been subdivided into the series and stages shown in the accompanying table. The names of the stages of the Pegus are those adopted by geologists of the Burmah Oil Company but they are now in general use by the Geological Survey of India, while the latter's Eocene stage names are used by all geologists in Burma. The divisions of the Pegus proposed by E. Vredenberg have not been found generally applicable. The most typical development is between latitudes 19° and 22°.

System	*Series*	*Stage*	*Thickness* (feet)
Irrawaddy	Mio-Pliocene		5,000–11,000
		UNCONFORMITY	
Pegu	Miocene	Obogon Alternations	Up to 3,000
		Kyaukkok Sandstones	Up to 5,000
		Pyawbwe Clays	Up to 3,000
		UNCONFORMITY	
	Oligocene	Okhmintaung Sandstones	0–5,000
		Padaung Clays	Up to 2,500
		Shwezetaw Sandstones	2,000–4,000
	Eocene	Yaw Stage	1,000–2,000
		Pondaung Sandstones	Up to 6,500
		Tabyin Clays	25,000 (?)
		Tilin Sandstones	
		Laungshe Shales with the Paunggyi Conglomerates	

Lower and Middle Eocene.

The thick Laungshe Shales form the most important part of the Lower Eocene. The predominant beds are dark-grey well-bedded, and often concretionary shales. Conglomerates at the base and at various higher horizons have been distinguished as the Paunggyi Conglomerate in the Minbu District and the Swelegyin Conglomerate farther north in the Pakokku District ; these conglomeratic beds vary from thin grits to thick boulder-beds, and are in places associated with quartzitic sandstones. The Tilin Sandstones show considerable variations in lithology and thickness and cannot everywhere be differentiated. The Tabyin Clays are a group of greenish-yellow shales which locally include thin impure coal seams : farther north in the Upper Chindwin District the Ngapun Alternations of greyish-green mudstones and grey sandstones with some calcite and lignite are probably equivalent. Fossils are not abundant in the Lower and Middle Eocene of Burma but the foraminifera indicate a correlation with the Laki and Khirthar Series of India. The Laungshe Shales include *Assilina granulosa*, *Nummulites atacicus*, and *Operculina canalifera*. The Tilin Sandstones contain *Arca*, *Cerithium*, *Crassatella*, *Natica*, *Ostrea*, *Turritella*, etc. The Tabyin Clay fossils are rare ; they include *Arca pondaungensis* and *Nummulites vredenburgi*. In the southern part of Burma the Lower and Middle Eocene have not been examined in detail but they are more arenaceous and apparently much thinner. Thin bands of limestone contain *Assilina granulosa*, *Nummulites atacicus*, and *Nummulites vredenburgi*.

Pondaung Sandstones.

The Pondaung Sandstone Stage forms wooded hills rising in places to over 4,000 feet and often forming magnificent scarps. The stage consists of massive coarse greenish sandstones with fossil wood and occasional bands of shale and clay which are mostly blue or grey, although some are red or purple. Near the base the shale bands increase in number and streaks of carbonaceous matter are developed. At the top there is usually a rapid passage into the Yaw Stage. The fossils include *Ampullina*, *Arca*, *Barbatia*, *Callista*, *Cardita*, *Ostrea*, *Vicarya*, etc., and indicate an Upper Eocene age. When traced northwards the stage includes freshwater beds, and in the Pakokku District near Myaing G. de P. Cotter has described sandstones with highly coloured clays containing reptilian and mammalian remains ; the following genera have been identified by G. E. Pilgrim :

Anthracohyus, *Anthracokeryx*, *Anthracothema*, *Indolophus*, *Indomeryx*, *Metamynodon*, *Sivatitanops*. In the Pondaung Range at the base of the stage there are conglomerates which in the hills farther east become boulder-beds; these contain gneiss, schist, and dolerite boulders.

Yaw Stage.

This is in general 1,000–2,000 feet thick and consists mainly of soft blue shales, but shows much lateral variation and includes limestones, sandstones, ferruginous conglomerates, and much carbonaceous matter. The stage exhibits a rich foraminiferal and molluscan fauna of Upper Eocene age including *Aulica*, *Cardium*, *Chama*, *Corbula*, *Cypraedia*, *Gosavia*, *Gypsina*, *Leda*, *Lucina*, *Meretrix*, *Nummulites*, *Operculina*, *Orthophragmina*, *Ostrea*, *Pinna*, *Solen*, *Sunetta*, *Tellina*, *Velates*, *Venus*, and many other genera. At the top (south of latitude 21° 5′) occur the Velates Beds which consist usually of highly fossiliferous, calcareous, ferruginous conglomerates with *Velates perversus*.

Shwezetaw Sandstones.

This stage forms well-wooded ranges of hills which are generally intermediate in altitude between those formed by the Pondaung and Okhmintaung Sandstones. G. W. Lepper records that though there is no apparent unconformity there is a sharp palaeontological break between the Yaw Stage and the Shwezetaws, the break marking the boundary between the Eocene and the Oligocene: many families of foraminifera and mollusca die out and the Yaw Stage with its rich assemblage of fossils of many orders and genera forms a strong contrast to the poorly fossiliferous Shwezetaws which overlie it. The Shwezetaw Stage, usually about 3,000 feet thick, exhibits considerable lateral variation, but is essentially arenaceous with a local development south of latitude 20° of more argillaceous sandstones and sandy shales with marine fossils, the upper part of the stage becoming predominantly shaly. Northwards there is a tendency to the development of a continental facies but the identification of the Shwezetaws beyond latitude 22° is open to doubt.

Padaung Clays.

The Padaung Clay Stage is usually about 2,000 feet thick and consists of blue concretionary shales (rather than clays) with very thin sandy bands which become more important towards the top and are richly fossiliferous. Northwards from latitude 20° the shales thin and there are more interbedded sandstones. Southwards the shales increase and pass down without a break into the upper part of the Shwezetaw Stage. The fauna has many more genera than are found in the Shwezetaws, the commoner molluscan forms including *Athleta*, *Cardita*, *Cardium*, *Chione*, *Clavilithes*, *Conus*, *Corbula*, *Cypraeorbis*, *Eumargarita*, *Genotia*, *Hindsia*, *Hipponyx*, *Meretrix*, *Nucula*, *Olivella*, *Ostrea*, *Pecten*, *Pinna*, *Pleurotoma*, *Surcula*, *Tellina*, *Tritonidea*, *Turritella*, etc. The commonest genera amongst the foraminifera are *Globigerina* and *Nodosaria*. The fossil evidence indicates an Oligocene age, probably Middle Oligocene. Although many of the genera range up into higher groups, many species are restricted to the Padaung Clays. The stage was termed the Sitsayan Stage by E. W. Vredenburg but the shales at Sitsayan are of higher horizon (Lower Miocene and not Oligocene); the term has also been used for lower rocks and for the whole range from the Shwezetaw Stage to the Pyawbwe Stage. It is therefore best to discard the name.

Okhmintaung Sandstones.

The Okhmintaung Sandstone Stage, where well developed, forms low wooded hill-ranges. The thickness of the stage is very variable, as an important break in the succession occurs at or near the top. In places the Okhmintaung Sandstones exceed 5,000 feet in thickness, but in some areas the stage is missing. It consists mainly of massive, argillaceous, and conglomeratic sandstones with sandy shales and (locally) bands of hard shelly limestone. Fossils are fairly numerous in a few localities and show a general correspondence with those of the Padaung Clays, all the genera mentioned in the preceding paragraph being found, although many are relatively less abundant and there are some differences of species. The fauna as a whole is less characteristic than is that of the Padaung Clays.

Vredenburg had recognized the probability of an unconformity between the Upper and Lower Pegus, and the restricted occurrence of a sandstone of variable thickness at the top of the Lower Pegus, but the significance of the break was not appreciated until its rediscovery by F. E. Eames of the Burmah Oil Company. The unconformity corresponds with the one between the Surma and Barail Series of Assam, and below the Murree Series of the Punjab. It is probable that a closer examination of the Okhmintaung Sandstones would throw light on the details of the unconformity, and might lead to a modification of the view that the principal break occurs *above* the sandstone.

Pyawbwe Clays.

The Pyawbwe Clay Stage is typically about 2,000 feet thick and consists of grey, sandy, concretionary shales with thin fossiliferous sandstones and conglomerates. There is a general tendency for the stage to become more sandy towards the north, and to assume a continental facies with very few fossils. In the Upper and Lower Chindwin Districts the Natma Beds, consisting of brightly coloured mottled shales with subordinate sandstones and grits, have been assigned by E. J. Bradshaw to the Pyawbwe Clay Stage ; still farther north the proportion of grit increases. Similar beds occupying part of the Myittha Valley near Gangaw are known as the Maw Gravels. The fossils found in the more southerly exposures of the Pyawbwe Clays include many of the genera mentioned as being common in the Padaung Clays but there are differences in relative abundance and in species. The common Pyawbwe Clay forms include *Arca*, *Batissa*, *Capsa*, *Cardita*, *Chlamys*, *Conus*, *Corbula*, *Cucullaea*, *Isocardia*, *Leda*, *Lithodomus*, *Lucina*, *Meretrix*, *Nucula*, *Sigaretus*, *Tellina*, *Teredo*, *Tibia*, *Turritella*, etc., lamellibranchs being more abundant than gasteropods. The fauna is of Lower Miocene age, probably Aquitanian.

Kyaukkok Sandstones.

The Kyaukkok Sandstone Stage consists of soft, medium-grained, false-bedded, yellow and brown sandstones with thin shale partings, and sandstones with calcareous concretions rich in fossils. Beds of fine alternations of yellow sand and shale also occur. Near latitude 20° the stage is about 2,500 feet thick, but to the south (where it is equivalent to the Prome Sandstones of W. Theobald) is usually thinner. Northwards the Kyaukkok Sandstones thicken to over 4,500 feet near latitude 21° but beyond this thin again (owing to the Irrawaddy/Pegu unconformity). North of latitude 21° 15′ the stage develops a continental facies with quartz conglomerates and a " Red Bed " which attains a maximum thickness of 400 feet. In the Upper Chindwin District the stage is probably represented by a group of massive sandstones containing a few quartz pebbles and with subordinate beds of clay ; these sandstones have some resemblance to the Irrawaddy rocks. The Kyaukkok Sandstones of Central Burma contain a rich molluscan fauna indicating a Lower Miocene (probably Burdigalian) age. A number of the species are found in the Okhmintaungs but not in the intervening Pyawbwe Clays, and it is evident that the faunas of the different stages are influenced by differing environments. Almost all the genera listed as common in the Pyawbwe Clays occur in the Kyaukkok Sandstones, but some are comparatively rare. The commoner Kyaukkok forms include *Arca*, *Batissa*, *Callista*, *Cardita*, *Cardium*, *Cassidea*, *Chlamys*, *Conus*, *Corbula*, *Cucullaea*, *Harvella*, *Leda*, *Mactra*, *Meretrix*, *Nucula*, *Oliva*, *Ostrea*, *Parreyssia*, *Pitar*, *Telescopium*, *Tellina*, *Timoclea*, *Turritella*, etc. The fauna includes a greater proportion of gasteropods than are found in the groups above and below ; a fairly large proportion of the Kyaukkok species (especially lamellibranchs) are confined to this stage.

Obogon Alternations.

In a large part of the Western Outcrops the Irrawaddy/Pegu unconformity cuts out the uppermost division of the Pegu System but near latitude 19° and from latitude 20° to 21° (and probably again in the Chindwin region near latitude 23°) the Kyaukkok Sandstones are overlain by a group of alternations, the Obogon Alternations Stage. The maximum thickness is about 3,000 feet (possibly 5,000 feet in the Chindwin Valley), and the stage consists of alternating beds of sandstone and shale. In the south marine fossils occur but towards the north the fauna is of a brackish-water type and here the stage contains conglomerates and grey and purple gypsiferous shales. The fauna appears to be less rich than those of most of the other Tertiary stages but this is partly due to restricted opportunities for collecting. Most of the commoner Kyaukkok genera are represented, although in many cases by only a few specimens. The common genera in the Obogon Alternations include *Arca*, *Callista*, *Cardium*, *Conus*, *Meretrix*, *Oliva*, *Sunetta*, *Telescopium*, *Tellina*, *Turritella*, etc. The proportion of species confined to the stage is somewhat small. The fauna suggests a Middle Miocene age.

The Irrawaddy System.

The Pegus are overlain by the continental deposits of the Irrawaddy System : in the oilfields region the junction is sharply defined, and is clearly unconformable ; in one inlier the Irrawaddies transgress across more than 10,000 feet of Pegus in 10 miles. The system has been examined in some detail in the main syncline west of Yenangyaung, Singu, and Yenangyat. It is here divisible into two parts, a lower more arenaceous group 3,500–4,500 feet thick and an upper group of alternations of coarse arenaceous rocks and sandy clays about 7,000 feet thick. The lower part of the Irrawaddies consists mainly of soft false-bedded and massive coarse ferruginous sandstones with a few concretionary bands. A " Red Bed " and a " White Bed " are not uncommon at or near the base. The " Red Bed " is a clayey sand, mostly brick-red but in places mottled with yellow ; it may contain small quartz pebbles and also pebbles of clay coated with iron oxide. The " White Bed " is a brilliant white soft sandrock with kaolin. On the western flank of the syncline opposite Yenangyaung ferruginous conglomerates in the lowest beds give rise to a prominent scarp, but on the whole conglomerates are not numerous in this group. Fossil wood is abundant and there are thin lenticular bands of clay. In the upper group similar yellow ferruginous sandstones are associated with persistent beds of sandy clay, one of which is about 1,000 feet thick ; several of these beds have been traced for 25 to 30 miles and probably extend very much further. Most of the red clays show sufficient colour banding to enable the dip to be determined. Fossil wood is abundant, and towards the north conglomerates become fairly common ; the pebbles (which range up to 18 inches in diameter) include quartz, sandstone, mudstone, and igneous and metamorphic rocks. Near the top about 600 feet of beds consist mainly of gravelly conglomerates interbedded with soft argillaceous reddish sandstone. South of the oilfields region the Irrawaddies cover a very large area but no detailed information has been published.

The fossil wood, which is so abundant as to have attracted the attention of travellers early in the nineteenth century, includes trunks up to 50 feet in length. Dicotyledonous wood is most abundant, and the commonest species is *Dipterocarpoxylon burmense*. The vertebrate remains found in the lower part of the system include a few reptile bones and many mammalian species. The principal genera represented are *Carcharodon*, *Colossochelys*, *Gharialis*, *Aceratherium*, *Amphibos*, *Cervus*, *Hipparion*, *Hippopotamus*, *Hydaspitherium*, *Mastodon*, *Merycopotamus*, *Prostegodon*, *Rhinoceros*, *Stegodon*, *Sus*, *Taurotragus*, *Tetraconodon*, *Vishnutherium*. Many of the species are found in the Siwaliks of North-Western India ; they indicate a Pontian age for the lowest fossiliferous horizons and a Lower Pliocene age for higher fossil beds. The Irrawaddy System may thus be regarded as of Mio-Pliocene age. In the Chindwin region fossils suggestive of a Middle Miocene age have been found in beds assigned to the Irrawaddy System, but, as pointed out above, in the northern part of Burma it is difficult to determine the Irrawaddy/Pegu boundary and the beds with Middle Miocene fossils are probably the continental facies of part of the Upper Pegus.

(*c*) STRATIGRAPHY—THE INLIERS

The preceding descriptions apply to the outcrops flanking the old rocks of the Arakan Yoma. East of these is the broad stretch of Irrawaddy rocks; within this are many inliers of Eocene and Pegu rocks. In the northern part of Burma most of these expose the non-marine facies of the Pondaung Stage and of higher beds and there is little difference between the Pegus and Irrawaddies. The more southerly inliers expose Pegu rocks and some of them provide good examples of the discordance between the Irrawaddies and the Pegus. In some of the more northerly areas Irrawaddy beds may overlap on to the Eocene.

(*d*) STRATIGRAPHY—THE PEGU YOMA

To the east of the main Irrawaddy outcrop there is a belt in which Upper Pegus (Miocene) are exposed in closely-folded anticlines. In the south (in the Pegu Yoma) the divisions of the Western Outcrops can be recognized but farther north the Miocene is a monotonous succession of sandstones with subordinate shales and the Irrawaddy/Pegu boundary is difficult to determine.

(*e*) STRATIGRAPHY—GENERAL

The data summarized in the preceding paragraphs show that there is a general tendency for a northward transition from marine to brackish-water and thence to freshwater beds. The evidence at present available, although by no means complete, does not suggest that there is any marked divergence between the lithological boundaries and the palaeontological stages, and accordingly it has not been found necessary to distinguish between the lithological divisions described above and stages or zones based on the faunas.

(*f*) STRUCTURE

Between the older rocks of the Arakan Yoma on the west and those of the Shan Plateau on the east the Tertiary rocks occupy a large elongated basin or geosynclinal trough extending from the extreme north of Burma to the coast near Rangoon and Bassein. Within this, two principal directions of folding can be distinguished, one approximately north-south, and the other approximately W.S.W.–E.N.E. The principal structural features of the north-south system are :—

(*a*) The main Chindwin-Irrawaddy syncline, a short distance east of the Western Outcrops.

(*b*) A belt of volcanic rocks, in the northern part of which the pre-Tertiary basement is exposed.

(*c*) An area of close folding in and north of the Pegu Yoma.

(*d*) A narrow belt of more open folds in the Sittang Valley.

The cross-folding has produced lines of uplift crossing the main syncline—

(*a*) near Monywa, latitude 22°,

(*b*) north of Thayetmyo, latitude 19° 30′,

(*c*) near the southern margin of the Irrawaddy Delta, latitude 16°.

The result has been to divide the main syncline into three basins. The importance of these cross-folds is shown by differences in the stratigraphy of the three basins and in the distribution of oilshows.

The Main Syncline.

Northern Basin.—The main syncline can be traced at least as far north as latitude 26° 30′, its axis being for many miles very near the course of the Chindwin River. Between the syncline and the northern continuation of the Arakan Yoma there is an area of complex folding in which Eocene rocks are exposed. To the east of the synclinal axis there are several lines of thrusting and these also bring up Eocene rocks; the thrusts hade westwards, the best known being the one bounding the Mahudaung Range. Within the syncline, lying athwart its central line, is the Indaw anticline (23° 30′) on which there is a small oilfield. The main syncline shows strong northerly and southerly pitches between latitudes 21° 45′ and 22° 50′, Upper Eocene beds being exposed along the axis between latitudes 21° 55′ and 22° 5′: nevertheless the southward continuation of the syncline is quite clear.

Stratigraphically the northern basin is distinguished by the development of a facies of Pegus very similar to the Irrawaddies, and by the absence or poor development of Oligocene rocks. The Pyawbwe Clay Stage is the lowest Pegu division that has been identified with reasonable probability in the northern basin and although it is underlain by sandstones, the age of these is doubtful owing to the paucity of marine fossils.

Central Basin.—The pitch of the main syncline is reversed south of latitude 22° and probably 30,000 feet of post-Eocene beds come into the basin. On the west there are anticlinal structures in echelon within the Western Outcrops, but the syncline is the first major structure to the east of the Arakan Yoma. Immediately east of the syncline is the Sabe-Yenangyat-Lanywa-Singu-Yenangyaung-Ondwe line of anticlines ; towards the southern end of this line the Minbu anticline intervenes between the syncline and Ondwe. Farther east is another line of uplift, a continuation southwards of the Mahudaung uplift—this includes the Myaing, Pagan Hills, Gwegyo, and Yedwet folds, and for the most part is bounded on the east by the southern continuation of the Mahudaung thrust. These two lines of uplift both die out in a broad basin of Irrawaddy rocks near Taungdwingyi.

The main synclinal axis continues south-south-eastwards, and although it develops a strong pitch as it approaches the cross-uplift and consequently becomes much less prominent, the syncline is not crossed by any fold and can be followed through to the Irrawaddy outcrop south-west of Thayetmyo. To the east of this part of the syncline there are several lines of folding which, like the Minbu fold, begin as noses projecting into the eastern flank of the main syncline.

Southern Basin.—The main syncline can be traced south-south-eastwards from the Thayetmyo District and with increasing pitch it again becomes prominent east of Prôme, but then reaches the alluvium of the Irrawaddy Delta. On both sides of the syncline near Thayetmyo and Prome there are several folds, but for the most part the anticlines are smaller, more sharply folded, and more closely spaced than those farther north, and there is a tendency for the folds to strike south-east rather than south-south-east. South of latitude 18° exposures are limited to the edges of the basin, the remainder of the area being covered by alluvium. On the eastern edge of the alluvial area there are close folds which can be regarded as part of the Pegu Yoma system.

Central Volcanic Belt.

Almost throughout its course the main syncline follows the general trend of the Arakan Yoma, and its axis is for the most part about thirty miles to the east of the Yoma foothills. About forty miles farther east a belt of volcanic rocks appears to indicate an uplift which never attained the same importance as the Arakan Yoma. The extinct volcanoes of Taungthonlon (5,600 feet) and Popa (4,981 feet) are conspicuous features of this belt and near Monywa there are exposures of granite and diorite which mark the emergence of the pre-Tertiary " basement ". Farther south in the Pegu Yoma (the range east of the

Delta) there are intrusions of dolerite. The volcanic belt may be continued southwards and south-south-westwards to link up with the volcanoes of Narcondam and Barren Island, the latter possibly not yet extinct. Although often referred to as the Popa line or the volcanic line, the breadth of the belt including volcanic rocks is in places as much as 20 or 30 miles.

The Pegu Yoma.

In the Popa region the volcanic belt divides the main syncline from a broad strip of more closely folded rocks which are for the most part Upper Pegus (Miocene). Southwards from Popa the intensity of folding increases and in the Pegu Yoma the volcanic belt, here much narrower, lies within rather than to the west of the area of tight folding. Northwards from Popa the folding is less intense and Irrawaddy beds occur in the synclines. Farther north much of this belt is occupied by alluvium.

The Sittang Valley.

The Sittang Valley is mainly alluvial but along the western edge there are Irrawaddy and Pegu rocks with more gentle folding than in the adjacent Pegu Yoma.

(*g*) GEOLOGICAL HISTORY

The geological history of the Tertiary area of Burma has been discussed in various papers. It has generally been supposed that the Tertiary rocks were laid down in a long narrow gulf bounded by the Arakan Yoma on the west and divided into two parts by a central longitudinal ridge which was approximately along the line of the central volcanic belt. L. D. Stamp has discussed this hypothesis in some detail and has stated that—

> "The whole history of the Tertiary period in Burma may be summed up as the story of the infilling of the twin gulf by river-borne sediments from the north and by marine sediments from the south."

This simple conception does not explain the distribution of the older Tertiary rocks. Although there is no doubt about the general tendency of the Tertiaries to pass from a marine facies in the south to a non-marine facies in the north, there is also evidence that a great thickness of Cretaceous and Eocene rocks was deposited in the Arakan Yoma area, and some reason to believe that the Eocene shore-line ran roughly north and south but tended to move farther and farther east as deposition proceeded. Since a large part of the Arakan Yoma is made up of Eocene rocks it is difficult to see how this area can be regarded as the western border of an early Tertiary Burma gulf. It seems more probable that during much of the Eocene epoch the western shore of the gulf was formed by the remnants of Gondwanaland (roughly Peninsular India and the Shillong Plateau), and so lay far to the west of the Arakan Yoma. The eastern shore may have been somewhere beneath the eastern flank of the main syncline and for part of the time may have been formed by the western edge of the central volcanic belt. It is likely that Eocene and Oligocene movements both included some uplifts of the Arakan Yoma that were sufficient to produce islands, but there seems no likelihood of there having been a barrier during the greater part of Eocene times.

On the whole deposition kept pace with the sinking of the Assam-Burma gulf until well on in Oligocene times. There was then a pronounced uplift, the effects of which are perhaps more clearly seen in Assam, where the emergence and erosion were greater. At the time of maximum regression very little of the gulf can have remained submerged. With the late Oligocene or early Miocene transgression the sea spread east of the central volcanic belt, and this may have formed some sort of dividing line between two parts of the gulf. The western boundary of the gulf cannot be fixed with certainty ; presumably part of the Arakan Yoma remained as a partial barrier between Burma and Assam, but the distribution of Miocene rocks (for instance the great thickness of marine Miocene sediments immediately west of the Arakan Yoma—which may amount to nearly 30,000 feet in the Akyab District) suggests that some of the Arakan Yoma and its northerly continuation was submerged during part of Miocene times.

By this time renewal of movement along the cross-uplifts had probably already had some effect in beginning a separation between the three different basins of what was afterwards to become the main syncline. Movements with this direction were certainly prominent during the next important folding—which separated the Pegu and Irrawaddy periods. It is probable that these movements brought about the complete separation of the Burma and Assam areas of deposition ; by then the Burma area had become almost silted up, and the effect of these pre-Pontian movements was to convert the region into a continental area in which a capping of red lateritic soil was formed in many areas. Large rivers, the forerunners of the present Irrawaddy and Chindwin, would however continue to pour deposits into the gulf from the north, and meanwhile the important folding movements which were responsible for producing the main anticlines and synclines of the Tertiary basin had begun. Further depression of the basin occurred as the folding progressed, but the rivers continued to pour in masses of sediment and the area never again became submerged by the sea. It is evident that the structure of the Tertiary belt was largely determined by these Pliocene movements, since the Irrawaddies have been involved in all the major folds and thrusts. These late movements were in the main from the east and produced the general north-south strike which dominates Central Burma, but it may be surmised that the considerable variations in trend (noticeable especially in the northern part of Burma) reflect the influence of the Shan Plateau and the Assam spur of Gondwanaland.

Sub-aerial denudation of the anticlinal crests was presumably in progress whilst deposition was still going on in the synclines; a plateau was developed in the central part of Burma and on this were formed the lateritic " Plateau Red Earth " and the deposits of gravel. With the subsequent denudation of this plateau the present-day landscape of the oilfield region began to take shape.

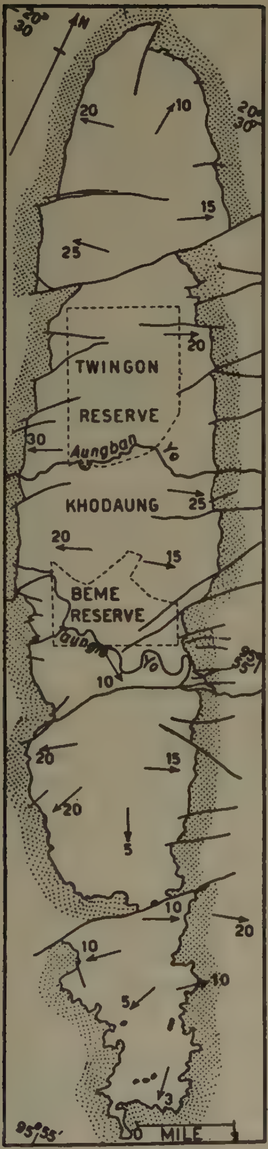
IV. THE BURMA OILFIELDS

(*a*) *Yenangyaung Field.*

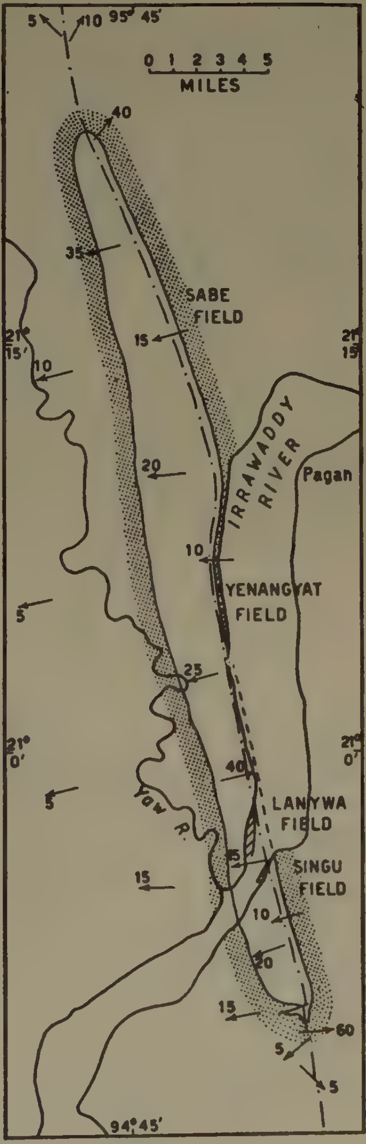
The Yenangyaung field is an elongated dome exposing Kyaukkok Sandstones (Miocene), the junction between this stage and the overlying Irrawaddy System being marked by a thin but persistent " Red Bed " and " White Bed ". The fold is slightly asymmetrical, the west flank having dips up to 50° and the east flank up to 40°, and is crossed by numerous dip-faults. These nearly all hade and downthrow to the north with throws varying from 50 feet to 400 feet and are locally of importance in influencing oil/water margins.

An interesting feature is the occurrence of mud-veins in the southern portion of the field. They are described by Pascoe, who says :—

> " Veins of mud are . . . especially numerous on the western half of the anticline. . . . They extend well into the Irrawaddy Sandstone westwards and pass into the Beme Reserve and a few into the Irrawaddy Sandstone on the east. The colour of the clay varies from a slate to a chocolate brown, but is different from the stratified clay it pierces. Fluxion structure can often be made out, but not between the stratified clays and the veins which cut vertically across them, though horizontal veins may be found above or below stratified clay. The edges of the clay stratum can sometimes be seen slightly turned up where the vein cuts across it. The veins often contain, along their sides, impure calcareous matter or selenite, sometimes showing crystal faces and may then be found weathered out and projecting from softer beds in the form of buttresses. In other places the veins are more easily weathered than the sandstone in which they occur. One of these near the western boundary has weathered



TEXT-FIG 3.
The Yenangyaung Field.



TEXT-FIG. 4.
The Singu, Lanywa, Yenangyat, and Sabe Fields.

From geological maps by the staff of the Burmah Oil Company.
The Irrawaddy/Pegu boundary is distinguished by stippling in the lower beds of the Irrawaddies.

> out leaving two parallel vertical smooth walls of sandstone 5 feet apart between which a road runs. This is unusually thick, the average being about 1 foot across. In some cases a little relative movement has accompanied the formation of the fissure. The veins are vertical or at high angles and the majority are at right angles to the anticlinal axis : consequently the horizontal direction of their outcrop is approximately 60° E. of N. to 60° W. of S. and the hades have a northward tendency. Dr. Noetling speaks of these as veins of 'eruptive mud', and this appears to be the most probable nature of the phenomenon, the mud being derived from ordinary Pegu clay beds at no great depth. They very probably were intimately connected with by-gone mud volcanoes which usually occur on the crest of anticlines, and were no doubt caused by the local strain between the two folding movements. . . . The fact that in this mud vein area there is scarcely any oil at all, but immense quantities of gas, is also suggestive since gas is undoubtedly the *raison d'être* of mud volcanoes."

As recorded above, this field has been yielding oil for probably several centuries. Two tracts known as Twingon and Beme were being worked by the Burmans at the end of the eighteenth century, the right to dig for oil being vested in twenty-four heads of families known as *Twinzayos* who could sell their right only with the consent of the other *Twinzayos*. After the annexation of Upper Burma in 1886 these rights were recognized by the British Government, who demarcated the Twingon and Beme areas as "Native Reserves" of 295 and 155 acres respectively. Most of the reserved area was divided into circular "well-sites" of 60 feet in diameter touching—and in some cases even overlapping—one another, and up to twelve sites per annum were allotted to each of the *Twinzayos*. In addition there were in all 164 small areas of irregular shape known as "State Wells" which fell to the Crown and were eventually leased to the original Burmah Oil Company. The government levied a royalty on the oil won from the reserved areas and it was arranged that any well owner might sell or lease his right to any other person or to a public company.

Prior to 1889 oil was obtained only from surface seepages (i.e. from outcropping oilsands in several of the steep-sided creeks which cross the inlier) and from wells dug by hand. Pascoe in *The Oilfields of Burma* gives a clear account of the operation of digging these wells :—

> "The Burman . . . is still seen at Yenangyaung in the midst of modern machinery, laboriously digging his five feet square shafts. These shafts are boarded up with wooden planks and in the old days with much difficulty reached a depth of 300 feet. Dr. Noetling describes the diggers going down with their eyes bandaged so that no time should be lost at the bottom in getting accustomed to the darkness, and being brought to the surface again in a state of complete exhaustion. The man, practically nude, was lowered on a rope over a crude pulley by a string of coolies and, in a well about 250 feet deep, took ¼ minute to reach the bottom. After half a minute of frantic digging or loading of pots or baskets in an atmosphere of gas, he was hauled up again during the next two minutes and then required about half an hour's rest before he was sufficiently recovered

do go down again. In such a deep well he could not make many more than 20 descents in a day. The earthen pots or wicker baskets of diggings are always hauled to the top on a separate rope. The light by which the digger works is flung down to him by a mirror at the mouth of the well. Such a primitive arrangement speaks more for patience than for ingenuity. Since Dr. Noetling's time, however, from the latter half of 1896 a decided improvement has been introduced in the form of a diving dress, air being pumped down by two coolies who turn the handles of an air pump. This operation as well as that of lowering and raising the digger is generally entrusted to the members of his family. In this way a man is enabled to stay at the bottom of the well for an hour or more, and depths of 400 feet or slightly more have in consequence been reached. Little less than two years are required to attain such a depth, whereas a machine drill will do the same in a week or ten days. Greater depths could no doubt be reached, but the Burman now finds it more profitable to dispose of his well-site to one of the European companies than to work it at all. Dr. Noetling also describes their method for breaking through the hard bands of calcareous sandstone met with in the wells, which is in reality much more effective and ingenious than it sounds. A pear-shaped mass of iron about 150 lbs. in weight is suspended over the mouth of the shaft by a thin rope passing over a bamboo: by means of a looking-glass the bottom of the well is examined and the weight shifted until it is exactly over the part to be struck, after which the rope is cut with a knife by a dexterous vertical blow against the bamboo, and the weight falls to the bottom fracturing the sandstone. In a well 256 feet deep the momentum attained would be 19,200 foot pounds and the shock of the impact can be felt on the surface for some distance around. Although the operation of sending a man down and hauling up first the man and then the weight seems ridiculously laborious, two or three such performances are sufficient for most hard beds."

In 1900 the yield from hand-dug wells reached a maximum of nearly 600 barrels per day, but is now less than one-tenth of this.

The first well completed by machinery was drilled by the Burmah Oil Company in Khodaung on the south bank of the Aungban Yo, and was finished in 1889. This well was only 727 feet deep but other early wells were even shallower; one of them, B.O.C. No. 8, 350 feet deep, has produced for over fifty years and still gives a small production. It was not until 1895 that rich production was obtained. Until 1906 the Burmah Oil Company held the field with the *Twinzayos*, but in 1907 the Rangoon Oil Company (to be distinguished from the company of the same name from whose ashes the original Burmah Oil Company arose) began to lease well sites from the *Twinzayos* and by 1908 four companies were in operation. In later years still further companies were floated, with the result that the Twingon and Beme Reserves became a veritable forest of derricks, many of them situated on sites only 60 feet apart.

The remainder of the field is divided into much larger holdings and here the wells are more widely spaced. The output of the field rose gradually until 1899 and then more rapidly, there being a particularly large increase in 1908; peak production was reached in 1916, with 16,000 barrels per day. Oil is obtained from depths down to 5,000 feet; the development of the deeper sands has been on the east flank and down the pitches of the dome.

(*b*) *Singu Field.*

The Singu field (latitude 20° 55′) lies just to the south of the Irrawaddy River at the southern end of a Pegu inlier, 39 miles long, which stretches northwards through Yenangyat and Sabe to latitude 21° 22′. The field, like Yenangyaung, is on an elongated dome but the fold is much more asymmetrical than Yenangyaung and the steep flank is to the east instead of to the west. Dips on the east flank rise quickly to 80° and are slightly overturned at the Pegu-Irrawaddy boundary; on the west flank the dips increase gradually to a maximum of 20°–25°. Some cross-faults are present of which the most northerly hades and downthrows to the south, the remainder to the north. The most southerly fault known has an important effect on the distribution of the oil, which is banked up on the southern (upthrow) side; in general, however, there are fewer cross-faults than at Yenangyaung.

The major portion of the field is leased to the Burmah Oil Company (Burma Concessions), Limited, and the first well was drilled by that company's parent company in 1902. Production mounted rapidly to 2,500 barrels per day in 1905 and to nearly 7,000 barrels in 1919; in 1938 the output for the first time exceeded that of Yenangyaung. The number of wells so far drilled exceeds 1,000. Oil is found in a thick series extending from about 1,400 feet below the surface to about 3,800 feet and there are as many as twelve to fifteen oilsands. At the south end of the field, south of the southernmost fault, production is found in various sands between about 3,500 and 5,000 feet. The field is truncated to the north by the Irrawaddy River and part of the river bed has been reclaimed by the Burmah Oil Company by the building of a retaining wall in the river. Three companies only are operating at Singu (the Burmah Oil Co. (Burma Concessions), Ltd., the British Burmah Petroleum Co., Ltd., and the Pyinma Development Co., Ltd.), and owing to the greater depth of the first oilsand there has been no development by hand-dug wells as at Yenangyaung, and consequently no closely-drilled " Reserves ".

(*c*) *Lanywa Field.*

The Lanywa field is situated on the right bank of the Irrawaddy, on a sand-bank reclaimed from the river between the Singu and Yenangyat fields by the Indo-Burma Petroleum Company, Limited. At Singu there is only a slight northerly pitch at the point where further exposures are hidden beneath the river, and at Lanywa, where exposures are next seen three miles farther north, there is gentle southerly pitch. It was at one time thought that Lanywa was the southerly continuation of the Yenangyat field and that the prospects of the area were hopeless as the nearest oilpools of Yenangyat had given place to edge-water some miles to the north. This seemed to be confirmed by the fact that early wells drilled north of Lanywa were unsuccessful. The Indo-Burma Petroleum Company geologists, however, established that the Singu and Yenangyat structures are in echelon, that the crest near Lanywa may be considered as lying on the Singu rather than on the Yenangyat axis, and that although southerly pitch is present near Lanywa there was reason to believe that a change to northerly pitch occurred not far to the south.

In the river to the south of Lanywa a large sand-bank occurred which was covered only at high water. In 1914 a well was begun on this sand-bank but had to be abandoned as it was a menace to shipping. In 1919 another well was drilled by the Indo-Burma Petroleum Company—this time on the shore south of Lanywa. This well found a small production of oil from two sands (thus indicating that some at least of the Singu oilpools extend under the river to Lanywa) and encouraged the Indo-Burma Petroleum Company to build a retaining wall to stabilize the sand-bank and avoid danger to navigation. The first well on the reclaimed area was started in 1927 and since that time more than fifty wells have been drilled ; production has recently been about one-sixth of the Singu output.

(*d*) *Yenangyat–Sabe Field.*

The Yenangyat and Sabe fields lie on the same long line of folding as Singu and Lanywa, though the Yenangyat and Lanywa axes are slightly in echelon. From the point where the crest of the Yenangyat fold appears from beneath the river near the village of Lanywa, there is a gradual rise in the elevation of the crest for about five miles to a minor culmination ; about five miles farther north there is a more marked summit near Yenangyat village, and another twelve miles farther the main summit of the structure is reached near Sabe. A long narrow field has been developed at Yenangyat and separate smaller ones on the southern summit and at Sabe. The structure at Yenangyat and Sabe is similar to that at Singu and Lanywa—i.e. a steep (in places overturned) and faulted east flank and a gentle west flank, with dips mainly of 15°–20°. There are a few cross-faults but in general this long anticline is remarkably free from such disturbances.

The Yenangyat field has been producing oil for many years. "Springs of petroleum" opposite Pagan were mentioned by Buckland in 1827, and T. Oldham, who visited Yenangyat in 1855, suggested that the area might be worth exploiting. Hand-dug wells were probably started about 1864 but have not yielded more than about 20 barrels per day; very few of these wells are now in existence. Most of the oilsands are shallow—500 to 1,500 feet near the Yenangyat summit. Production from drilled wells began in 1893 and reached a peak ten years later when the field yielded 1,500 barrels per day. The small field at Sabe was first developed in 1908; oilsands were found down to 1,800 feet but they were thin and poorly productive and production ceased in 1922.

(*e*) *Minbu–Palanyon–Yethaya Field.*

The three small fields of the Minbu District lie on a single anticline running approximately north-south, close to and on the right bank of the Irrawaddy some 20 to 30 miles south of Yenangyaung. The general structure is that of a steeply-folded asymmetrical anticline, the east side being overturned in places and overthrust, the west flank also being very steep. Pascoe has described the structure as not unlike that of Yenangyat but having reached a more advanced stage. The fold is somewhat irregular in shape. In the north, near the town of Minbu, it is almost symmetrical, with dips of 75°–80° on the west and on the east a zone of vertical or overturned beds succeeding a strike-fault barely half a mile from the crest; southwards the zone of steep beds narrows and is succeeded on the east by dips of 30°–40° which flatten out farther east. The strike-fault develops into a thrust which replaces the crest in many places so that over much of the fold a true crest is developed only locally and for short distances. The west flank maintains its generally steep character throughout the major part of the fold but becomes gentler in the extreme south. The fold pitches fairly strongly in the north near Minbu town and in the south near the Yethaya area, but in between, over a length of some eight miles, the crest undulates, small and irregular domes often disturbed by cross-faults being developed at intervals.

The Minbu fields have never had a large production, the peak being in 1928 with 400 barrels per day. The oil has been produced mainly from three areas, Minbu (or Shwelinban) on the northerly pitching end of the fold, where outcropping oilsands are reached in shallow wells, Palanyon near the culmination of the anticline, and Yethaya on a small dome on the east flank at the southern end of the fold. The Minbu wells are near the mud volcanoes that have been described by Pascoe, Barber, and others; the largest cone had a height of 15 feet in 1855, 40 feet about 1890, 80 feet in 1910, and 30 feet in 1933.

(*f*) *Indaw.*

The solitary Indaw field in the Upper Chindwin District is 175 miles north of any of the other important fields; it was discovered by the Indo-Burma Petroleum Company, and began regular production in 1918. Barber described the structure as an elongated asymmetrical dome running N.N.E.–S.S.W.; the inlier of Pegu rocks exposed is thought to be about nine miles long and two miles wide at its widest point. In this part of Burma the Irrawaddy and Pegu rocks closely resemble one another; the boundary between the two systems is taken by C. T. Barber at a coarse quartz grit, in places ferruginous but not closely similar to the "Red Bed" at Yenangyaung. The Indaw structure has a gentle west flank (10°–15°) and a steep east flank (50°–65°) and in the southern half of the inlier a subsidiary crest is developed parallel to the main crest and about half a mile west of it. A few transverse and strike-faults occur, mainly of small throw. Oil is obtained from shallow sands and production has been in the neighbourhood of 150–200 barrels per day. Deep drilling has proved difficult owing to high-pressure gas-sands.

(*g*) *Yenanma.*

The small Yenanma field is situated about 22 miles west of the Irrawaddy River in the Thayetmyo District. Oil is obtained at depths between 300 and 1,200 feet and appears to occur on a monocline close to important cross-faults. Cotter suggests that accumulation is due to sand lenses which thin out as they approach the surface. However, it would appear that some at least of the oilsands reach the surface since there are several important seepages and mud volcanoes close to the field; it was in fact these oil occurrences which prompted the drilling of the first well early in this century. The field is now operated by Yenan Mines, Ltd., the successor of the Indo-Burma Oilfields (1920), Ltd., which started work in 1922. The production of this field is small but drilling is still being carried on.

(*h*) *Padaukpin.*

The Padaukpin field lies about nine miles west-north-west of the town of Thayetmyo. A long steep anticline with dips up to 60° exposes Okhmintaung Sandstones, and shallow wells, including some Burmese hand-dug wells, have obtained a small production. Between 1922 and 1926 the output was in the neighbourhood of 50 barrels per day but it is now negligible.

(*i*) *Pyaye.*

The Pyaye dome, exposing an inlier of Pegu rocks about two square miles in area, occurs nine miles south-west of Thayetmyo. The structure is slightly asymmetrical with dips up to 45° on the eastern flank and 35° on the western flank. The Indo-Burma Petroleum Company found sixteen gas-sands in a well drilled to 2,525 feet. The volume from the largest sand was measured as 39 million cubic feet per day and the roar as it escaped from the well could be heard at Thayetmyo. The shutting in of the well proved to be a difficult undertaking but was eventually accomplished without accident.

V. STRATIGRAPHICAL DISTRIBUTION OF PETROLEUM IN BURMA AND ITS SOURCE

In his paper at the 1933 World Petroleum Congress, G. W. Lepper points out that oil and gas seepages are particularly numerous in the rocks bordering the main syncline. In the northern or Chindwin basin all the surface oilshows are in the upper half of the Eocene—many of them in the uppermost part of the Pondaung Sandstone. Although the oilsands of Indaw are in the Pegus (probably Upper Pegus) the oil may have migrated upwards from the Eocene. In the central basin, although most of the oilshows are in the Eocene there are many at higher horizons associated with faulting, and the production from the main fields is also from higher horizons, mainly Oligocene. In the southern basin, oilshows are not found in the Eocene but in the higher horizons (mainly Miocene), and they are comparatively few in number. Surface oilshows are unknown from the large area east of the central volcanic belt.

As regards the source of the oil found in the main fields, the consensus of opinion is that little upward migration has taken place and that the oil was formed in the shales close to the sands in which it is now found. The probability of fairly extensive lateral migration is generaly conceded. For example, Lepper writes : " It is concluded that most of the oil of the main oilfields has migrated into them from the sediments of the median syncline. . . . It is thought that as the sediments became compacted by continuous deposition above them, oil and salt water were expressed and moved laterally to the coarser and more permeable deposits of the margins." Pascoe wrote in *The Oilfields of Burma* : " Although nearly all evidence is against upward migration from abyssal horizons across the strata, there are no arguments against local lateral migration in any one sand." Stamp has also expressed much the same view : " The rapid alternation of beds of impervious clay and porous sands which characterizes the Peguan almost precludes the possibility of extensive migration of oil. The evidence supports the view that the oil of Burma originated in the beds in which it is now found and only *lateral* migration has been important."

VI. ACKNOWLEDGMENTS AND REFERENCES

The details of the foregoing summary of the geology of the Burma oilfields have for the most part been taken from the work of the geologists of the Burmah Oil Company, but the main outlines of the Tertiary geology were determined by the early work of the Geological Survey of India and much detail has been added by their later work ; the various *Memoirs* and *Records* have been of great assistance to the geological staffs of the oil companies.

A full bibliography of the early literature on the oilfields of Burma is included in E. H. Pascoe's memoir ; this was brought up to 1935 in the memoir by C. T. Barber ; it is therefore unnecessary to record any but the most important of the earliest references. G. de P. Cotter and E. L. G. Clegg have also given full lists of writings bearing on the Tertiary geology. There are many references to the geology of the oilfields in the annual and quinquennial reviews of mineral production published in the Records of the Geological Survey of India, and the annual reports of the Survey include much information about the Burma Tertiaries.

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The Yorkshire Dogger

II. Lower Eskdale

By R. H. RASTALL and J. E. HEMINGWAY

THE outcrop of Dogger described in this paper covers an area 12 miles in length, stretching S.S.W. from Whitby up the lower course of the River Esk and its tributary valleys of Iburndale, the Murk Esk Valley, Egton Grange, and Glaisdale. Unlike the coast natural exposures are few and unsatisfactory and in Lower Eskdale in particular are only encountered where becks from the surrounding moors cut through the massive boulder clay plug which partly fills the main valley. Other exposures occur in abandoned alum works, disused ironstone adits and small quarries. The outcrops cross diametrically a part of the Whitby Basin, the Eskdale Dome, the Goathland Syncline, notch the main Cleveland Dome (Lees and Cox, 1937),[1] and range in height from 35 to 500 feet O.D.

In the past, before the working of the Cleveland ironstone, the Dogger was mined for ironstone at Glaisdale, Grosmont, and Beckhole. Contrasted with later great developments this was on only a small scale, which is not surprising when the rapid appearance and disappearance of the various rock-types is appreciated. It should be remembered, however, that the working of the Dogger or "Top Seam" was the precursor of the opening up of the Middle Lias ironstone field of Cleveland, at first at Grosmont and later in the richer region farther north, near Guisborough and Skelton.

Except for a few outstanding localities the Dogger is essentially unfossiliferous within the area under consideration. Its apparent rapid lithological change between isolated exposures has long been recognized (Fox-Strangways, Reid, and Barrow, 1885), and in the absence of widespread fauna it has been assumed that this is solely due to lateral variation of one bed. Detailed fieldwork, however, has shown that this is not so. Four facies developments of the Dogger have been established on lithological and petrological criteria alone, only two of which are contemporaneous. These are :—

1. Whitby Basin facies, a massive sideritic sandstone, identical

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[1] It is unlikely that the depth of the Dogger on the downthrow side of the Whitby Fault is as great as is indicated on the map accompanying that paper (more than — 400 ft. O.D.). The maximum depth is approximately — 280 ft. O.D.

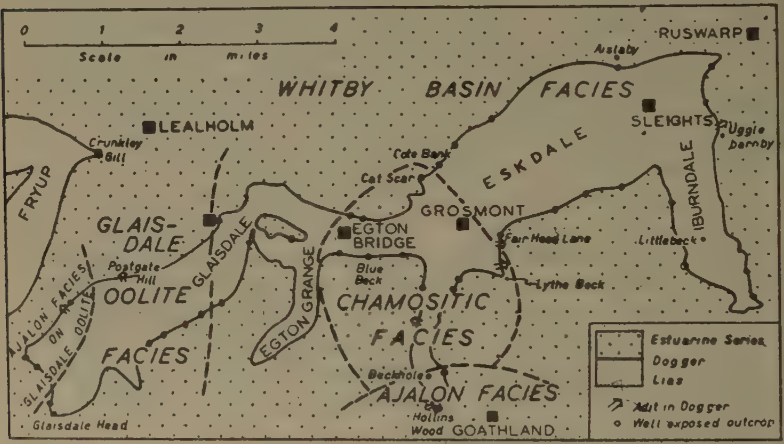
in every way with the Dogger of the coast between Kettleness and Peak (Ravenscar).

2. Glaisdale Oolite facies, a dense fossiliferous ironstone with chamosite ooliths set in a siderite matrix.

3. Chamositic facies, comprising a thinly-bedded series of chamositic sandstones and oolites.

4. Ajalon facies, so named from an exposure near Ajalon Farm, Great Fryup; usually characterized by massive sandy grey chamosite-oolites.

The areal distribution of these four rock types is shown in Text-fig. 1. The petrological characters of each will first be



TEXT-FIG. 1.—Areal distribution of the four Dogger facies in Lower Eskdale and its tributary valleys.

Note.—The Dogger of Fryup Dale is deferred to a later paper. For the geographical relationship of Dogger of this area to that of the coast see Text-fig. 1 in Rastall and Hemingway, 1940.

described, with typical exposures, followed by their field relationships to each other.

In only a few localities does the Dogger, in any of its facies developments within this area, exceed 12 feet in thickness and averages rather less. With two exceptions it rests non-sequentially upon Alum Shales (Whitbian) and it is always overlaid by deltaic sandstones and shales of the Lower Estuarine Series. In south-west Glaisdale, however, in four localities between Applegarth Hall and Park Dike up to 6 feet of pale grey-brown silty clays with abundant *Serpula* tubes are exposed beneath the Dogger. These beds have been proved in adjacent dales to be of *striatulum* age and their occurrence here extends the area of Yeovilian rocks in the region to the west as previously defined (Macmillan, 1932). Also from less certain evidence east of Glaisdale it would appear that the Dogger here rests on Peak Shales of the *lilli-variabilis* zone, while east of Egton Bridge it overlies Alum Shales of *commune-bifrons* age.

In late Yeovilian times North-East Yorkshire was gently folded and peneplaned. High Whitbian and Yeovilian strata were preserved in a downfolded area of which Glaisdale forms the eastern boundary and subsequently the Dogger was deposited non-sequentially upon these beds.

WHITBY BASIN FACIES

From Ruswarp to Grosmont, in Lower Eskdale, the Dogger is represented by a tough, massive, sideritic sandstone, speckled white by kaolinitized felspar and usually unfossiliferous. This represents the westward extension of the Whitby Basin facies of the coastal region already defined (Rastall and Hemingway, 1940). It is best exposed in the New Alum Works (formerly Spence Works) 1,200 yards south-west of Sleights Church, where it attains its thickest development. There is no justification for the threefold subdivision previously adopted (Tate and Blake, 1876; Rastall, 1905). The Dogger is here a massive rock 15 feet thick, with strongly marked spheroidal weathering and a thin pebble bed of phosphatized and rounded fragments of Whitbian cementstone at the base.

To the west the Dogger may be easily traced as far as Grosmont. Throughout this distance it diminishes in thickness but maintains its lithological character, though the number of derived ooliths, small in the east, increases slightly westwards. It is deeply weathered, forming a series of crusts of brown, limonitic sandstone which may be over a foot in thickness. It is doubtless this highly ferruginous appearance which resulted in the profitless opening of ironstone adits in this facies, particularly at Ugglebarnby. When fresh this rock is strikingly different, with a blue, crystalline appearance due to high carbonate content, as may be seen in the 10 ft. outcrop in a small waterfall in the western branch of Cote Bank Wood.

Considerable exposures of Dogger also occur in the upper part of Iburndale, between Falling Foss and Littlebeck. These sections, now badly overgrown, have been described by the senior author (Rastall, 1905), and a large fauna was recorded, although no diagnostic fossils have yet been found. The rock is deeply weathered and the preservation of the fossils, as a result, is poor, being only as moulds and casts.

Fossiliferous Dogger of Whitby Basin facies is exposed in a gully below the west end of Aislaby, near the Woodlands footpath. The fauna, which is similar to that in Iburndale, has already been recorded (Tate and Blake, 1876): a revised measurement of the section is as follows:—

	ft.	in.
Lower Estuarine Series		
Massive yellow sandstone	20	0
Dogger		
Yellow speckled sandstone	4	0
Shales with three rows of siderite mudstone nodules, some oolitic	3	6
Fresh, blue sideritic sandstone, fossiliferous and with pebbly base	1	10
Upper Lias		
Alum Shale (seen)	20	0

It may be noted that this fossiliferous locality lies midway between similar exposures at Mulgrave and Sandsend, 2 miles to the north, and Littlebeck to the south. These three aligned points may well be outcrops of one continuous fossiliferous bed formed as a shallow water shell bank subparallel to the Kettleness Ridge.

A second area within which sideritic sandstone of the Whitby Basin occurs is to the west of Egton Bridge, in Arnecliffe Woods and near Glaisdale village. Boulder clay and landslips mask the outcrops in this district and exposures are few. The Dogger is most easily seen by the side of the track up Snowdon Nab leading to the Rosedale road, where 12 feet of brown speckled sandstone, massive and in large blocks, rests without the usual pebble bed on Whitbian shales. This same facies may be traced, though difficult of access, through the upper part of West Arnecliffe Wood. Farther south-west in the small Bank House Beck, an 8 ft. exposure of Dogger shows a blue, oolitic siderite rock, very dense and heavy, like that at Stoupe Brow Alum Works (Rastall and Hemingway, 1940). Although this rock bears a superficial resemblance to the Glaisdale Oolite facies there are important differences, since the ooliths are here derived and kaolinitized as in the rest of the Whitby Basin and not primary as in the Glaisdale Oolite.

On the north-western side of Glaisdale, above the Esk and east of Upper Under Hill, 8 feet of sideritic sandstone is exposed. This also has been tried for an ironstone, but it differs considerably from the Glaisdale Oolite to the south, which has been more profitably worked. A coarser and thicker variant of the Whitby Basin facies in the Glaisdale district occurs in East Arnecliffe Woods where 11 feet is exposed, the upper 8 feet of which contains coarse quartz fragments.

Although no diagnostic fossils have been found in the Whitby Basin facies in Lower Eskdale, sufficient evidence has been found in the same series of beds at Mulgrave, 2 miles to north, to date it as of upper *opalinum* (Lower Aalenian) age. The faunal assemblages of Lower Eskdale, it may be added, are similar to but not identical with that at Mulgrave.

Detailed petrographical descriptions of this facies of Dogger in Lower Eskdale are unnecessary. All specimens show the same characteristics as the coast sandstones, namely wide spacing of the clastic constituents in a siderite matrix, which over considerable areas in a thin slice may be quite free from sand ; white specks of felspar and derived and kaolinitized chamosite ooliths in small quantity. The heavy mineral assemblage is strangely limited, uniform, and uninteresting, consisting only of zircon, rutile, and tourmaline. No anatase has been found and garnet occurs only in very small quantity at Aislaby.

One specimen from Aislaby split vertically showed macroscopically detritus of varying textures arranged in loops and curls in the siderite matrix, in a manner strongly suggestive of slumping of the unconsolidated sediment before lithification.

GLAISDALE OOLITE FACIES

A part of the Glaisdale Oolite was at one time worked for ironstone and the adits and tips at Postgate Hill on the north-west side of the dale provide the best-known inland section of Dogger. From this locality a large fauna, particularly rich in Terebratulids, *Trigonia denticulata*, and *Homoeorhynchia cynocephala* has been recorded (Tate and Blake, 1876 ; Rastall, 1905 ; Macmillan, 1932). The adit exposure now shows :—

	ft.	in.
Lower Estuarine Series		
Grey shale with much wood	2	0
Dogger		
Blue-grey flaggy chamositic sandstone	5	0
Hard oolitic ironstone (seen)	4	0

Only the lower bed is of Glaisdale Oolite facies, and it is impossible now to ascertain its full thickness, as the base is hidden. The Geological Survey Memoir records a total of 12 feet, which probably did not include the chamositic sandstone (Fox-Strangways, Reid, and Barrow, 1885). Not all this rock was used as an ironstone, the lower fossiliferous part being rejected.

At the present time the ironstone is best exposed in a bluff above the stream at Glaisdale Head, where the following was measured :—

	ft.	in.
Lower Estuarine Series		
Soft sandstones, shales, and coal	15	0
Dogger		
Coarse striped flags with rare indeterminate lamellibranchs and streaks of siderite-mudstone	5	0
Low grade ironstone, variably oolitic and sandy, with a 2 ft. fossiliferous band near the base	8	6
Upper Lias		
Alum Shales (seen)	15	0

The upper bed of the Dogger is not regarded as a part of the Glaisdale Oolite facies. From evidence elsewhere it is known to represent a lateral variation of the Ajalon facies.

On the south-east side of the dale between Winter Gill and Bank House Beck sections are numerous. They show a good deal of minor variation, in particular that the ironstone is less well developed than on the opposite side of the dale. Thus by the track to the moor above Low Gill Beck Farm is exposed :—

	ft.	in.
Lower Estuarine Series		
Coal	1	0
Whitish sandstone	10	0
Grey silty shales	5	0
Black carbonaceous shales	2	0
White sandstone	3	6
Dogger		
Oolitic siderite-mudstone with layers of greenish speckled sandstone	1	3
Pebble bed : many pebbles over 3 inches in length, predominantly oolitic ironstone, in a matrix of oolitic siderite-mudstone	1	0
Speckled sideritic sandstone	1	0
Sideritic sandstone	3	0
Sandy oolite with fossils	4	6
Upper Lias		
Alum Shales (seen)	1	0

To the north-east the Dogger attains a maximum of 15 feet and is represented in the main by sandy chamosite-oolites, blue-hearted when fresh but weathering to a soft brown rock which has in the past been described as a sandstone. The lower 2 feet is richly fossiliferous with the same fauna as at Postgate

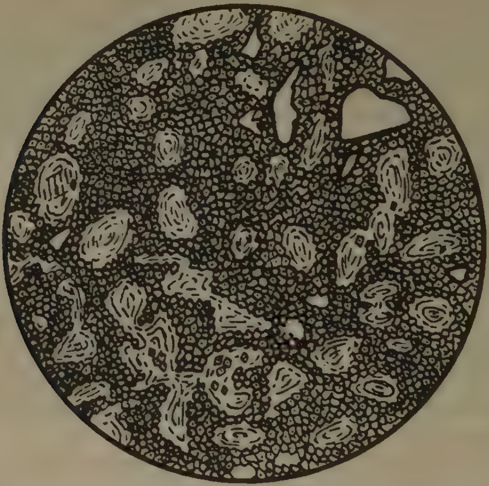
Hill on the opposite side of the dale. In the weathered rock only casts are preserved and when fresh fossils may be extracted only with difficulty, their shells being preserved in black calcite.

Farther to the north-east the Dogger thins steadily until 300 yards east of Bank House it is represented only by a pebble bed 1 foot thick while still farther in this direction sideritic sandstone of the Whitby Basin facies is found.

When examined petrologically the lowest, fossiliferous division of the Glaisdale succession, which was discarded by the ironstone workers, shows a certain amount of variation. Fresh specimens from between Bank House and Low Gill Beck are pale grey rocks with black calcite fossils in a fine-grained crystalline matrix. The sand fraction is abundant, mainly quartz and quartzite, but with some felspar (perthite and plagioclase), all of which is well sorted, of small grain size and for the most part sharply angular. No ooliths were detected in the slice and flakes of chamosite are very rare. The matrix is a variable mixture of calcite and siderite, and in some places calcite is so abundant that the rock may almost be described as a sandy limestone. It is the rapid weathering of carbonate matrix which causes the formation of the light, spongy, limonite-stained rock. The heavy mineral concentrate was unusually large and includes several grains of cleaved garnet, the only occurrence in this facies in Glaisdale. Rutile and anatase are so abundant as to appear in some thin sections.

That part of the Glaisdale Oolite originally worked as an ironstone varies in macroscopic appearance according to the relative proportions of ooliths, sand, pebbles, and matrix and to the degree of oxidation of the matrix. In the best-known locality at Postgate Hill the rock contains an unusually high proportion of ooliths and is considerably oxidized, so that it cannot be regarded as typical. From the south-east side of the dale, as above Bank House and New House, much fresher material may be obtained. Here are fine-grained, pale brownish-grey rocks spotted by grains of white, grey, and black mudstones and oolites less than 2 mm. in diameter. A thin slice shows pale green chamosite ooliths with the usual concentric structure and some sand grains in a siderite matrix of typical tiny rhombohedra with dark cores (Text-fig. 2). The ooliths, which are numerous though patchily arranged, average less than 0·2 mm. in diameter. It is noteworthy that a large proportion show some degree of distortion (spastolithic structure), which, since these structures cannot survive transport, clearly indicates that the ooliths are primary. They always show pitted margins, being indented by the rhombs of the siderite matrix.

Slices cut from comparatively fresh material from Postgate Hill adit are similar to the foregoing. The ooliths are primary since many show dumb-bell as well as other distorted structures. A little kaolinitization is seen here and there in the stained slices, which also reveal the usual amount of interstitial chamosite binding the siderite rhombs in the matrix. Notwithstanding the superficial resemblance of this rock to the Boulby type of oolite, these two ironstones differ essentially in origin (Rastall and Hemingway, 1940). The derivation from other sources and the consequent leaching of the ooliths of the latter ironstone would also appreciably affect the metallic iron content of the rock.



TEXT-FIG. 2.—Glaisdale Oolite from Postgate Hill, Glaisdale, showing abundant ooliths, some spastolithic, with a small proportion of quartz fragments in a matrix of fine-grained siderite rhombs with dark cores. Magnification × 20.

CHAMOSITIC FACIES

This is confined to a limited area of about 5 square miles with outcrops round Grosmont, Egton Bridge, and in the valley of the Murk Esk. It is typically exposed in Crag Cliff Wood in a small waterfall 200 yards north of the Cleveland Dyke, thus :—

	ft.	in.
Lower Estuarine Series		
Massive yellow sandstone	10	0
Dogger		
Green, thin-bedded, speckled flags	12	0
Well-bedded chamosite-oolite with basal pebble bed, passing upwards into sandstones	5	0
Upper Lias		
Alum Shales (seen)	15	0

The green matrix of the pebble bed is sheared and slickensided due to squeezing between the pebbles, an unusual feature. In the oolite occur bedding planes crowded with comminuted lamellibranchs and some gastropods as well as carbonized wood fragments.

In the bed of the stream below Cat Scar, north of Grosmont, only 600 yards south-west of an outcrop of sideritic sandstone of typical Whitby Basin facies, is exposed at least 30 feet of flaggy green sandstone with numerous rows of siderite-mudstone nodules and small shale pellets. No oolites occur in this section and fossils are absent.

In the more easterly of the two becks running down to Egton Bridge on the north side of the Esk is an almost exactly similar rock in a very fresh condition, with however a feeble tendency to oolith formation in the chamosite matrix. In the western beck this is more pronounced, the rock showing a small proportion of chamosite ooliths.

Near the southern limit of the chamosite facies a roadside exposure above the blacksmith's shop at Beckhole shows 3 or 4 feet of deeply weathered chamositic sandstone, with a basal bed with pebbles up to 3 inches in length containing waterworn ammonite fragments of *striatulum* type. This section differs completely from an adjacent beck section of Dogger of Ajalon facies, only 150 yards distant.

The only fossils in these beds are broken lamellibranchs and gastropods which cannot be identified. No ammonites other than derived fragments have been found and it is therefore impossible to date this series.

When dry the sandstones of the chamosite facies are bright green in colour. Petrographically a specimen from Cat Beck is a sandstone of moderate texture, with well graded but extremely angular grains of quartz, some felspar and occasional flakes of green chamosite. The cement is fresh blue-green chamosite of an unusual tint enclosing scattered rhombs of siderite. This chamosite sandstone, typical of the Grosmont area, is almost identical with some of the characteristic rocks of the Runswick Lagoon (Rastall and Hemingway, 1940). This also applies to the chamositic oolites of this facies, as from Crag Cliff Wood. In thin section these show fresh green chamosite ooliths of moderate grain size, with bands of broken shells and wood. The cement is often deeply oxidized, but on analogy with other specimens, was undoubtedly chamosite.

AJALON FACIES

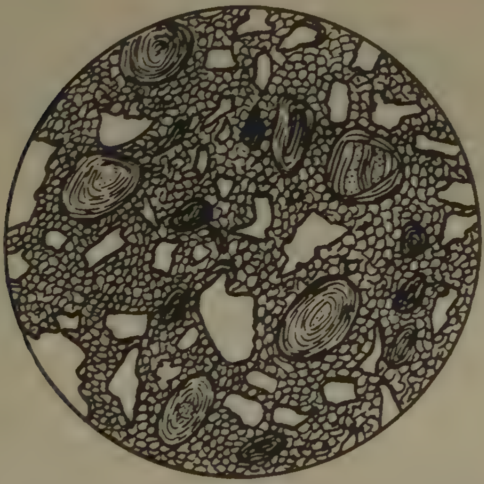
The term Ajalon facies is adopted from a section of coarse, grey, sandy oolite near Ajalon Farm, in Great Fryup Dale, outside the present area. In the tributary valleys of Lower Eskdale this rock type, easily recognizable in the field, occurs in two localities, near Beckhole, at the south end of the Murk Esk Valley and in south-west Glaisdale. It is typically developed in the latter dale and is best exposed in a fresh state in a roadstone quarry near the top of Common Lane, where it is 10 feet thick and rests on an attenuated representative of the Glaisdale Oolite. To the north-east it may be traced for at least a mile and it is again well exposed near the moor-track above Applegarth Hall, where it is 7 feet thick and has been tried as an ironstone. Farther north-east it thins out. Similarly to the south-east it becomes thinner as in Park Dike and after changing laterally into a banded, sandy rock with elongated lenses of siderite mudstone, it thins out completely. No fauna other than rare, ill-preserved lamellibranchs has been found, though wood fragments, both mineralized and carbonized, are common.

Near Beckhole, Ajalon facies of Dogger is seen in a scar on the north side of the Eller Beck about 100 yards above the bridge. Here the following section was measured :—

	ft.	in.
Lower Estuarine Series		
Massive yellow sandstone (base of washout)	25	0
Dogger		
Brown, sideritic grit with many pebbles	2	0
Brown, sandy oolite, deeply kaolinitized	1	2
Pebble-bed with pebbles as above up to 2 inches long in matrix as above	1	3
Pale green sandstone with much vitrainized wood	1	6
Upper Lias		
Siderite mudstone		4
Alum Shales (seen)	6	0

Only the upper three beds of Dogger have Ajalon affinities. The lowest closely resembles the sandstones of the Chamosite facies, which are exposed in force only 150 yards to the north.

Ajalon facies is strikingly exposed in Wheeldale Beck, south of Beckhole, where it outcrops along the walls of the post-glacial gorge and forms the waterfall in Hollins Wood. At least 16 feet of ironstone is seen resting with a slightly irregular and pebbly base on Alum Shales. The upper part of the seam was most highly valued as an ironstone. This is a flaggy rock, breaking into slabs rather more than an inch thick, which are beautifully ripple-marked and crossed by mollusc or worm tracks. The flaggy ironstone is itself banded with layers of chamosite-oolite alternating with broader bands of almost pure siderite, free from ooliths. This passes downwards through a more massive, fairly coarse, blue-grey oolite to a darker oolitic rock with a larger proportion of derived constituents.



Text-fig. 3.—Ajalon Oolite from Common Lane Quarry, Glaisdale, showing well-formed chamosite ooliths and abundant corroded quartz grains set in a relatively coarse-grained siderite matrix. Magnification × 20.

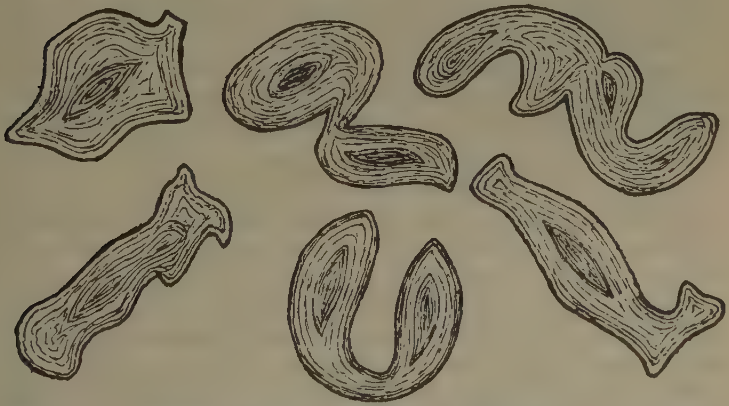
The ironstone thins rapidly northwards and on the west bank it is reduced to less than 2 feet in 400 yards. On the east bank of the stream the thinning is less pronounced, though, as has been indicated above, it changes to a thin sandy oolite with pebble beds in the Eller Beck (900 yards) and disappears 150 yards farther north.

Microscopically as well as macroscopically the Ajalon facies is highly distinctive (Text-fig. 3). Specimens from Common Lane quarry, for example, show chamosite ooliths averaging 0·3 mm. in diameter, which unlike the Glaisdale Oolite are very perfectly preserved, oval or circular in section, with sharp margins unindented by the matrix and nearly all without distortion. Their colour in ordinary transmitted light is pale yellowish-green and slight concentric zoning is shown, which is conspicuous under crossed nicols. The birefringence is rather variable, some ooliths appearing nearly isotropic, while in other instances it may be as high as 0·01. (It has been noted that in many ooliths slight alteration tends to increase the birefringence of chamosite.) Some are built round a core of flaky chamosite, though the majority have a sand-grain nucleus.

Rather coarse and fairly well-sorted corroded sand is very abundant, consisting mainly of quartz and microquartzite, felspar (perthite) being rather scarce. Flakes of chloritic chamosite occur with the usual properties and a slightly higher birefringence and a few shapeless lumps of chamosite consisting of an aggregate of small flakes. Among the small pebbles are isotropic phosphate rock (probably originally Liassic cementstone), a few small fragments of completely kaolinitized mudstone and pebbles of chamosite-oolite with an isotropic, phosphatized base. The matrix consists of fresh siderite in relatively large rhombs, as a rule without dark cores; shells are preserved in comby siderite.

These properties are shared by the grey oolite forming the middle part of the Dogger in Hollins Wood, south of Beckhole. Here, however, it passes downward into rocks of unusual type; they are too fine in grain to be called pebble beds and cannot be termed sandstones, since this usually connotes, by accustomed usage if not by definition, a considerable proportion of quartz sand. Originally they were undoubtedly fine, bedded gravels with a certain proportion of ooliths. Thin sections show layers of varying grain size, lenticular bands of fine siderite-mudstone, and fragments of wood. Most bands, except the mudstones, are notably oolitic. Some contain grains up to 3 mm. of a great variety of rocks, as well as quartz and felspar (usually perthite): these include oolites with a black, phosphatized matrix, phosphatized cementstone, sandstones with chamosite cement, and an unusual chamositic rock in which ooliths only show definitely with crossed nicols. Although all are probably derived from local rocks by contemporaneous erosion, none are known in situ. The ooliths of fresh, pale green chamosite vary much in size. Most are well formed, but there are many strangely distorted forms (spastoliths). All the ooliths are clearly primary and there is no kaolinitization. The matrix is coarse-grained, fresh siderite, which when bordering empty spaces shows well-defined rhombohedra.

The Ajalon types from the Eller Beck, particularly the brown sandy oolite, are similar to this, though without the wide variety of derived grains. An uncommon feature of this bed is the occurrence in the matrix of patches of interstitial kaolinite of considerable size. In many parts of the rock, where the clastic grains are large, siderite cement forms a shell of more or less constant width around each grain, the angular spaces between being filled up by kaolinite aggregates in which the characteristic rouleau structure is beautifully brought out on staining. There is nothing to show what mineral the kaolinite has replaced.



Text-fig. 4.—Spastoliths (distorted ooliths) of chamosite from the Ajalon facies of Dogger at Hollins Wood, Beckhole. × 50.

The kaolinitization of these rocks is doubtless of recent origin, due to the extreme wetness of the section and the consequent extensive alteration of the sediments.

The heavy mineral assemblage from Common Lane is unusual but characteristic of the Ajalon facies. The dominant minerals are anatase and brookite, with smaller amounts of zircon, rutile, garnet, staurolite, corundum, and chloritoid. The characters of the brookite have already been described (Rastall, 1938), when it was shown that several well-marked types of varying optical properties are present in the same rock, all being apparently authigenic. The heavy mineral assemblage differs completely from those of the other rock types in the area under consideration, but shows strong resemblance to those of the same facies in the dales to the west of Glaisdale. The significance of this fact has not yet been fully worked out and will be deferred to a later paper.

THE FIELD RELATIONSHIPS OF THE DOGGER FACIES

Although the recognition of the four facies types of Dogger in Lower Eskdale and its tributaries can be effected fairly readily, the inter-relation of one facies with the others is less easy to demonstrate. This is due to the lack of fossils throughout the Dogger as a whole, with certain outstanding exceptions, and to the paucity of exposures in critical localities. The lithological characters of each facies are sufficiently distinct to allow accurate correlation over short distances, and it may be added, heavy minerals are of some assistance. As will be shown below correlation between the Glaisdale Oolite and the Whitby Basin facies can be demonstrated on faunal evidence. The relationship of these to the other, virtually unfossiliferous facies can be shown only where two or more are found superimposed in field exposures.

The Whitby Basin and Chamositic Facies

The discovery of *Leioceras costosum* in Common Lane Quarry, Glaisdale, was sufficient to date the Glaisdale Oolite as of upper *opalinum* (Lower Aalenian) age (Macmillan, 1932). The faunal assemblage of this ironstone, rich in Terebratulids, *Homoeorhynchia cynocephala* and in lamellibranchs, is very characteristic and is similar to, but more extensive than those from Littlebeck and Aislaby in the Whitby Basin facies. Furthermore, sideritic sandstone of typical Whitby Basin facies from Rock Head Alum Works, near Sandsend, outside the present area, has been found to contain a large *Leioceras* of the upper *opalinum* zone. Clearly the Glaisdale Oolite and the Whitby Basin facies of Dogger are contemporaneous and may be correlated together.

A probable explanation for the difference in facies between the widely spread sideritic sandstone of the coast and adjacent areas and the more limited contemporaneous ironstone of Glaisdale may be deduced from exposures on the south-east side of Glaisdale, between Low Gill Beck and Bank House Brow Plantation. From the south-east the Dogger decreases within a mile from 15 feet of fossiliferous oolitic ironstone to a 1 ft. pebble bed. Immediately north of this latter exposure Whitby Basin facies sets in and may be traced through West Arnecliffe Wood. On analogy with the Kettleness Ridge (Rastall and Hemingway, 1940) it would appear that this localized pebble bed which marks the boundary between two distinctive facies is also the remnant of a deposit on a shallow water ridge or shoal raised tectonically during or immediately before Dogger times. On it no sediment other than the products of its own erosion, pebbles derived from Whitbian concretions, could accumulate, but it served as an effective barrier on each side of which distinctly different sedimentational conditions developed (Text-fig. 5*a*).

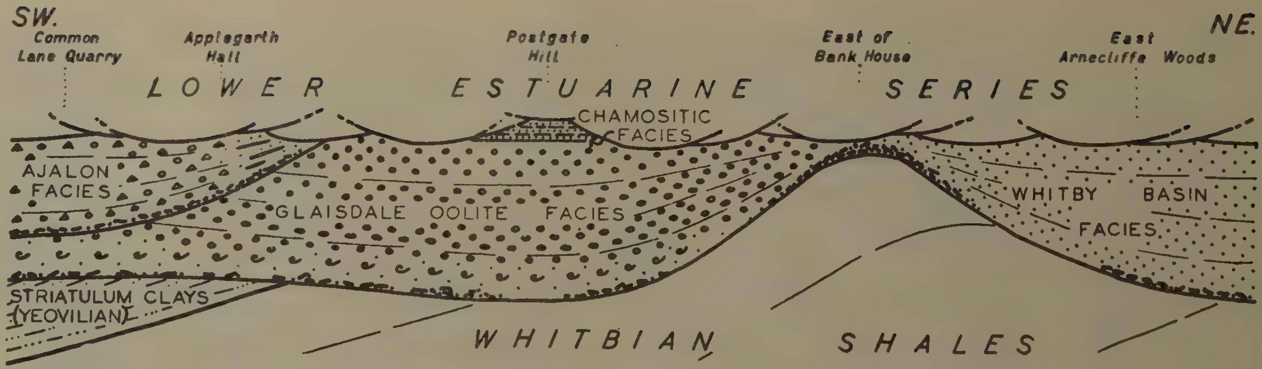
The Glaisdale Oolite probably accumulated in a lagoon where favourable chemical conditions and gentle agitation promoted the growth of chamosite ooliths and the co-precipitation of siderite. Except for the ridge to the east no boundaries for this lagoon are known. To the west, as seen in Common Lane Quarry, the ironstone thins steadily westwards as a result of subsequent erosion which preceded the deposition of the Ajalon facies in South-West Glaisdale, while farther west, in Great Fryup, the Glaisdale Oolite does not occur. Although it is recognized in Crunkley Gill, its northern, like its southern limits are purely conjectural. They are thought to be not far beyond the present outcrops. From this lagoon were derived a few ooliths which, kaolinitized and battered, occur in decreasing numbers in the sideritic sandstone of the Whitby Basin facies to the east.

Chamositic Facies

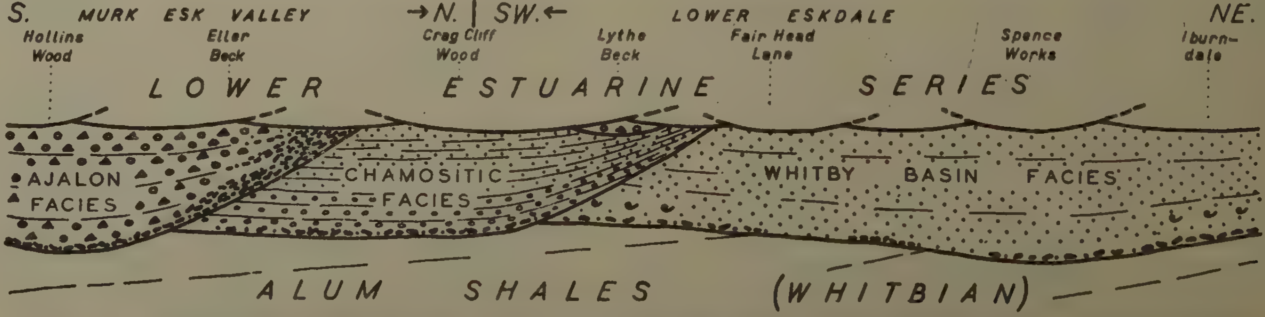
As has already been described the Chamositic facies of the Dogger very rapidly takes the place of sideritic sandstone of the Whitby Basin facies between Cote Bank and Cat Scar, a distance of 600 yards. The change is complete, and there is no trace of lateral transition. The relationship between the Chamositic facies and the other rock types can best be determined in exposures near the boundary of the main chamositic area. At Blue Beck, near Egton Bridge, for example, 4 feet of chamosite-oolite typical of the Chamositic facies (i.e. with chamositic cement) rests upon 6 feet of sideritic sandstone of Whitby Basin facies. Similarly south-east of Grosmont a poor exposure in an unnamed gully running into Lythe Beck, near a collapsed ironstone adit, show the following incomplete section :—

	ft.	in.
Dogger		
Blue-grey sandy ironstone (? Ajalon facies) . . .	2	0
Green sandstone with indeterminate lamellibranchs, wood fragments and worm tubes (Chamositic facies) . .	5	0
Sideritic sandstone with *Terebratula* (Whitby Basin facies) .	2	0

Clearly such sections indicate that deposition of the Whitby



TEXT-FIG. 5*a*.—Diagrammatic section of the Dogger of Glaisdale. Length of section 3½ miles.



TEXT-FIG. 5*b*.—Diagrammatic section of the Dogger of the Murk Esk valley and Lower Eskdale. Length of section 5 miles.

Basin facies preceded that of the Chamositic facies and other similar sections along the Murk Esk valley confirm this sequence.

There is little definite evidence to explain the absence of Whitby Basin facies within the limits of the chamositic area as shown in Text-fig. 1. This absence may be due either to non-deposition or to subsequent erosion and one point would appear to favour the latter alternative. Areas of non-deposition of Dogger or Whitby Basin facies are usually flanked by pebble beds up to a foot or more in thickness, but in this area no such pebble beds border the Whitby Basin facies. It is therefore more probable, though by no means certain, that subsequent erosion is responsible for the absence of sideritic sandstone in the Grosmont-Egton-Murk Esk area. Except for small localized patches the Whitby Basin facies was stripped from this area and chamositic rocks deposited in its place and upon its truncated margins.

There are indications that Chamositic facies was originally more widely spread than at present. At Postgate Hill 5 feet of chamositic sandstone rests upon Glaisdale Oolite while a similar succession also occurs in Crunkley Gill. This separation from the main chamositic area was brought about in late Dogger or pre-Estuarine times, when erosion over parts of North-East Yorkshire profoundly affected the continuity of the then existing Dogger deposits.

Ajalon Facies

The field relationships of this facies to the other rock types are relatively easy to determine. This is particularly true in south-west Glaisdale where the Ajalon facies takes the form of a broad lenticular bed, part of which is exposed in Glaisdale and the rest in Fryup. The maximum development of Ajalon facies in Glaisdale may be seen in a quarry and adjacent gutters in Common Lane, where the following was measured :—

	ft.	in.
Lower Estuarine Series		
Massive, felspathic sandstone	4	0
Dogger		
Pale chamosite-oolite with one band rich in carbonized wood fragments (Ajalon facies)	10	0
Sandy, fossiliferous ironstone (Glaisdale Oolite facies) .	3	0
Upper Lias		
Serpula clays (*striatulum* zone), seen	1	0
Alum Shales	—	

To the north-east and south-west the Glaisdale Oolite increases in thickness, while the Ajalon facies becomes thinner and sandier in the same directions. There is no indication that the Glaisdale

Oolite in Common Lane Quarry is a condensed representative of that facies. Its highly fossiliferous and sandy character, identical with the base of the fully developed Glaisdale Oolite demonstrate that this is an uneroded relic left after the greater part had been removed. Nowhere in this dale does the Ajalon facies cut through the Glaisdale Oolite, though in Hollins Wood, near Beckhole, it rests on Alum Shales throughout the length of the exposure in Wheeldale Beck.

The Ajalon facies of Glaisdale and Beckhole is not thought to take the form of channel-fillings or "washouts" in the accepted sense of the term. Such washout sediment is essentially derived from elsewhere, while the Ajalon Oolite with its fragile spastoliths and unaltered chamosite ooliths is clearly primary. Also washout deposits are usually unbedded and deltaic in origin, whereas the Ajalon facies is both bedded and marine. It is therefore held that the Ajalon rocks are deposits of an unusual mode of origin. Their deposition was preceded by slight uplift, when the older Dogger deposits, in particular the Whitby Basin facies, formed a low land surface which was dissected into small, shallow, marine embayments, separated by low-lying headlands. Such embayments would provide an ideal environment for the accumulation of Ajalon rocks. In the rather deeper medial areas ooliths would develop in gently agitated water, being co-precipitated with siderite. Nearer the shores, towards low-tide level, the banded sandstone with sideritic lenses would accumulate, as is now found at Glaisdale Head and which is clearly a lateral transition of typical Ajalon oolite. Other off-shore or bay-head sediments are now represented in the thicker pebble beds which usually flank the main oolite deposits in the field (e.g. in the Eller Beck, near Beckhole), while the abundance of wood fragments which characterizes this facies further supports this theory of its origin.

The embayments, never at any time deep, were gradually filled up by these marine sediments, which in the medial areas were predominantly of chemical precipitation and round the margins chiefly off-shore detritus. The final phase is well seen in Hollins Wood where ripple marks and worm tracks indicate that the embayment was built up almost to sea-level. Such conditions were followed by the deltaic deposition of the Lower Estuarind Series.

The field relations of the Ajalon Oolite can best be discussed with reference to the evidence in the dales to the west of Glaisdale, where these rocks are most clearly exposed. It is sufficient to say here that within the area under review it is the last of the three phases of Dogger deposition which can be recognized, since in Eller Beck it rests upon an attenuated representative of the Chamositic facies (p. 360). Farther west it can be shown that the Ajalon facies is one of the last of the complex sequence of Dogger sediments and closely related to the Black Oolite (Rastall and Hemingway, 1939) into which it imperceptibly grades upwards.

It should not be overlooked that in post-Dogger and pre- or early Estuarine times deep erosion channels were cut into and through the Dogger. These are now filled with massive Estuarine "washout" sandstone, which, particularly on the coast, break the continuity of the Dogger outcrop. Less localized erosion also affected the Dogger during the events which led up to the onset of deltaic conditions under which the Lower Estuarine Series were laid down and this undoubtedly removed a part of the Dogger over broad areas, leaving isolated patches of recognizable rock types far from their main areas of distribution. Clearly the Dogger of Lower Eskdale and adjacent dales represents only the balance of deposition during three separate marine phases over the erosion which succeeded each in turn.

SUMMARY

Within Lower Eskdale and its tributary valleys three thin series of Dogger deposits, all marine but largely unfossiliferous, may be recognized superimposed upon each other. Of these the sideritic sandstone of the Whitby Basin is the oldest and is of upper *opalinum* (Lower Aalenian) age. It covers a considerable area and is a continuation of the same facies which outcrops on the coast between Kettleness and Ravenscar. To the west the contemporaneous Glaisdale Oolite, a low-grade fine-grained sandy oolitic ironstone, was laid down in a more restricted marine lagoon where chamosite ooliths were precipitated together with crystalline siderite. Varying proportions of sandy detritus were deposited with the chemical precipitates, which materially reduce the value of the rock as an ironstone. In north-east Glaisdale the deposits of a shallow-water ridge or shoal can be recognized. This acted as a boundary between the two facies and permitted specialized conditions to develop to the west.

Subsequently erosion stripped off this rock type from an area of at least 5 square miles near Grosmont, where later was deposited a group of thin-bedded, fine-grained sandstone and oolites, green in colour and rich in chamosite (Chamositic facies). Originally these rocks had a greater areal extent than at present. Round the margins of their main outcrop they rest

on siderite-sandstone of the Whitby Basin facies, while farther afield isolated patches occur.

The third and final phase of deposition is seen in the Ajalon facies of south-west Glaisdale and Hollins Wood, Beckhole. These coarse-grained, low-grade ironstones, massive, very sandy, and pebbly chamosite-oolites with a siderite matrix, occur as lenticular or boat-shaped deposits, which in Glaisdale cut into but not through the Glaisdale Oolite. In Hollins Wood deeper erosion completely removed the pre-existing Dogger deposits and Ajalon facies now rests on Alum Shales of the Whitbian. Ajalon rocks are regarded as deposits laid down in shallow marine embayments cut in slightly uplifted earlier Dogger and their sandy, littoral equivalents are also recognized. At the edge of one of such bay deposits of Ajalon facies rest on a sandstone of the Chamositic facies, clearly indicating the sequence of events.

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The Brachiopod family Parastrophinidae

By J. K. S. St-Joseph, Sedgwick Museum, Cambridge

Parastrophinidae Ulrich & Cooper, 1938, emended

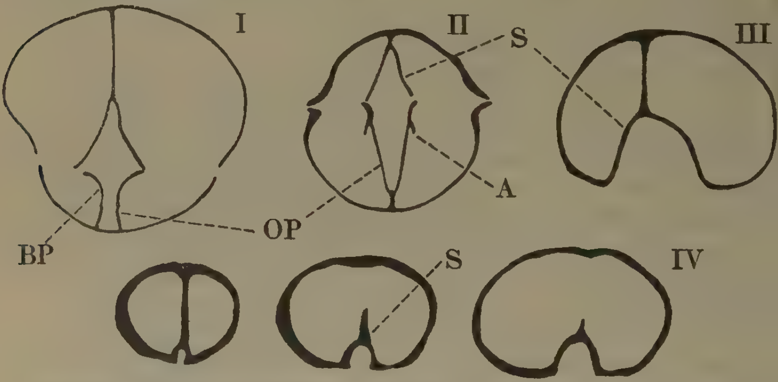
BICONVEX to plano-convex usually partly costate Protremata, without pseudodeltidium or chilidium so far as known. Of the two valves the dorsal is considerably the larger and more convex. The delthyrium is closed by the incurved dorsal umbo. Dentition simple ; strong teeth developed on dental-plates fit into sockets between the brachial-processes and the valve margin. The dental-plates unite to form a duplex spondylium. In the dorsal valve the alate cardinalia consist of short brachial-processes supported on outer-plates, which may remain parallel or converge to form a sessile cruralium or cruralium duplex. The muscles are attached within the spondylium in the ventral valve, while dorsally there is a central grouping of the adductor muscles on the inner surface of the valve below the cruralium.

Geological range—Upper Ordovician to Lower Devonian.

The reversal of the relative convexity of the valves together with the duplex spondylium and alate cardinalia comprising brachial-processes and outer-plates are the most characteristic features of this family. The high dorsal valve and the reverse curvature are the best guides in field determination. Little work has been done on the development of any members of the Parastrophinidae but in specimens of *Anastrophia internascens* 2 mm. long Beecher found (1901, pp. 337–9) the dorsal valve to remain shorter than the ventral until a length of 7 mm. had been reached. In these early growth stages the convexity of both valves is less than in the adult, though the dorsal valve still has the greater curvature and Beecher conjectured that in the embryonic shell the dorsal valve would be both the smaller and less convex. Figures of young specimens seem to show the delthyrium to be open (Beecher, 1901, pl. xvii, fig. 14*a*—*A. internascens* ; Hall, 1859, pl. xlviii, fig. 1*e*—*A. verneuili*), but it is possible that a pseudodeltidium may have been present and resorbed or destroyed later by the forward growth of the dorsal umbo for no trace of this structure has been noticed in the adult. In *Parastrophinella* and *Anastrophia*, in which the incurving of the dorsal valve is considerable, abrasion or resorption of the ventral umbo may occur, and there is such close contact between the two umbones in the adult condition as to leave no room for the passage of a functional pedicle.

For specific identification it is often necessary to examine the internal structure. This may be revealed in weathered specimens, but is usually too delicate to be exposed artificially by employing a dental drill. Thin sections, however, will give the necessary information and a single cross-section at about the level of the hinge-line is sufficient for identification. For detailed study serial transfers at small intervals have been taken from two or three examples of each genus, permitting the construction of enlarged models of the valves which show the internal characters. Frequently, natural casts will give useful information and it is by studying Hall and Clarke's figures of internal casts of "*Parastrophia*" *divergens*, *multiplicata*, and *latiplicata* that these species are here referred to *Parastrophinella*.

The Parastrophinidae resemble the Pentameracea in the possession of a duplex spondylium and cruralium but differ in their musculature. The spondylium (Text-fig. 1) is relatively small, seldom attaining to one-third of the length of the valve; widest at the level of the hinge-line, it narrows anteriorly, where the walls become parallel or slightly diverging. For some



TEXT-FIG. 1.—The Spondylium. I. Pentameridae, II. Parastrophinidae, III and IV. Syntrophiidae.

I.—Transverse section of *Pentamerus laevis* J. Sowerby (= *P. oblongus* auctt.). Zone 7b, Malmøy, Norway. × 2. Specimen A. 13503 Sedg. Mus., Cambridge.

II.—Transverse section of *Parastrophina hemiplicata* (J. Hall). Ordovician New York. × 4. From specimen B. 12939 British Museum (Nat. Hist.).

III.—Transverse section of a ventral valve of *Syntrophina carinifera* E. O. Ulrich and G. A. Cooper. Ozarkian Quebec, Canada. × 20. From specimen BB. 1026 British Museum (Nat. Hist.).

IV.—Three transverse sections of a ventral valve of *Syntrophia lateralis* (R. P. Whitfield). Canadian Vermont, U.S.A. × 5. From specimen BB. 1029 British Museum (Nat. Hist.).

A = ala; BP = brachial-process; OP = outer-plate; S = spondylium.

distance below the umbo it may remain sessile but towards the anterior it is always elevated on a rather slender duplex septum formed by the approximation of the dental-plates. The *Parastrophinella* series (Text-fig. 8) illustrates very well the development of a duplex spondylium from a sessile spondylium. The septum is reduced in height below the end of the spondylium and dies away as a small ridge. Its duplex character is clearly seen in thin-sections or transfers, the median plane of division continues to the outer shell-layers that compose the valve.[1] In the Syntrophiacea, with which the Parastrophinidae have often been grouped, the spondylium is of simplex type and may become free at its anterior end (Text-fig. 1), conditions never found in this family, and in the writer's opinion there can be no close relationship between the two.

Two structures can be recognized within the dorsal valve—brachial-processes and outer-plates (Text-fig. 2). The former are either parallel or diverge slightly towards the anterior, while the outer-plates extend from the brachial-processes to the floor of the valve and may remain discrete or converge so as to meet at or above the valve-floor, when they compose a cruralium. Each outer-plate is attached to a brachial-process, and the outwardly curved dorsal edges of the brachial-processes form the alae so characteristic of the family.

This account with the usage of the terms " brachial-processes " and " outer-plates " to describe structures homologous to those in the Pentameracea differs from Schuchert and Cooper's description of the dorsal interior. These authors (1932, p. 164) distinguish (1) brachial supports, (2) alar processes, (3) fulcral plates, and (4) supporting lamellae. Study of the growth-lines seen in transfers shows that the " alar processes " are only the outward turned edges of the brachial-processes, and the alate character of the cardinalia is due to the outer-plates being attached to the bases of the brachial-processes about the mid-point of their faces instead of along their dorsal edges as in the Pentameracea, and may be compared with the carinae present in *Clorinda* (St-Joseph, 1938, pp. 315, 319–320). The " fulcral plates " (3) consist of the thickened ventral edges of the brachial-processes which curve laterally to form small flanges serving as buttresses for the teeth. They appear to agree in position and function with the fulcral plates of the Orthoidea. The " supporting lamellae " (4) correspond to the outer-plates of the

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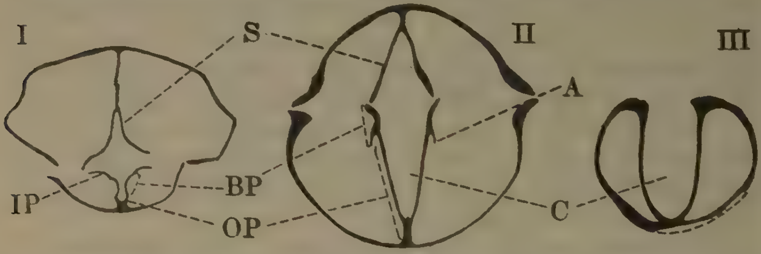
[1] Anteriorly the duplex character may be masked as in the Pentameracea, since the growth-layers become less clear, and statements that the spondylia of the Parastrophinidae are of simplex type are based on observations at the lower end of the septum only.

Pentameracea and unite the brachial-processes rigidly to the floor of the valve for the posterior half of their length. The outer-plates form a cruralium in *Parastrophina* and *Parastrophinella.* In the first genus this is elevated throughout on a duplex septum which continues beyond the end of the cruralium, in the second it is sessile but may be raised slightly towards the anterior. Although there is no trace of structures corresponding to the inner-plates of the Pentamerids the dorsal structures (Text-fig. 2) clearly conform to the same general type as do the Pentameracea, and differ from the Syntrophiacea where no separation into brachial-processes and outer-plates has been recognized. On grinding down specimens from the posterior end it is the outer-plates that often appear first owing to the incurving of the dorsal valve: the brachial-processes arise below the umbo and their dorsal edges gradually separate from the outer-plates.



TEXT-FIG. 2.—The Cruralium. I. Pentameridae, II. Parastrophinidae, III. Syntrophiidae.

I.—Transverse section of *Pentamerus* (*Pentameroides*), cf. *gotlandicus* N. Lebedev. Zone 7cβ, Ringerike, Norway. Natural size. Specimen A. 13507 Sedg. Mus., Cambridge.

II.—Transverse section of *Parastrophina hemiplicata* (J. Hall). Ordovician New York. × 5½. From specimen B. 12939, British Museum (Nat. Hist.).

III.—Transverse section of a dorsal valve of *Syntrophina carinifera* E. O. Ulrich and G. A. Cooper. Ozarkian Quebec, Canada. × 13½. Specimen BB. 1025, British Museum (Nat. Hist.).

A = ala; BP = brachial-process; C = cruralium; IP = inner-plate; OP = outer-plate; S = spondylium.

The Parastrophinidae have a simple dentition; the teeth project dorsally from the hinge-line at the lower corners of the delthyrium. In *Parastrophina* and *Anastrophia* they are rather prominent, blunt processes while in *Parastrophinella* the edges of the dental-plates are less thickened and hardly extend forward from the commissure. When the valves are in the position of life the teeth press closely against the outwardly curved margins of the brachial-processes which carry the main strain as the valves articulate. The dentition is thus of the same type as in the Pentameracea, and although the teeth are more strongly developed than in that group the valves must have been mainly held together by the mantle and the muscles. *Parastrophinella* shows the same tendency to reduction of the teeth found in *Pentamerus*.

It is well known from casts that in this family there was a central grouping of the muscle-scars on the inner surface of the dorsal valve below the cruralium, (Hall and Clarke, 1894, pl. lxiii, figs. 21, 24; Davidson, 1883, pl. ix, fig. 9; Reed, 1917, pl. xxii, fig. 41[1]), but in the available specimens the muscles have left little trace on the interiors of the valves. Published figures do not reveal clearly how far the impressions are muscle-tracks formed as the area of attachment moves forward during growth, but the usual four-fold division of the dorsal adductor-scars can be recognized. No scars have ever been reported on the inner surface of the ventral valve since the spondylium would serve as usual as an elevated muscle platform. The divaricator muscles, it may be assumed, were inserted in the dorsal valve posterior to the hinge-line between the outer-plates, or in the cruralium when the plates united to form such a structure. As is commonly the case in strongly biconvex Brachiopoda, the maximum movement that could be effected by the divaricator-muscles is extremely small owing to the extent of incurving of the umbones. Study of models of different specimens shows that the muscles must have passed between the brachial-processes (cf. Text-figs. 5, 9, 15),[2] but whereas in the Pentameridae both sets of muscles were inserted between the outer-plates or on a cruralium, in the Parastrophinidae the area of attachment of the adductors lay outside the outer-plates or below the cruralium —the more primitive condition.

There is a close relationship between the Parastrophinidae and Camerellidae (including besides *Camerella*, *Neostrophia*, *Idiostrophia*, and *Rhynchocamara*). In the second family duplex spondylia and cruralia may be present, but according to Ulrich and Cooper (1938, p. 248) the cardinalia are not alate, and these authors accordingly proposed the family Parastrophinidae (ibid., pp. 194, 248) to include *Parastrophina*, *Parastrophinella*, and *Anastrophia*. It is probable that in *Camerella* brachial-processes and outer-plates may be recognized but that they are attached edge to edge so that alae are not present. This would seem to be the condition from which the Parastrophinidae have developed.

[1] The figure shows a dorsal valve, not ventral as stated.

[2] In naturally weathered specimens the brachial-processes easily get broken, which may explain statements to the contrary.

TABLE SHOWING THE DISTRIBUTION OF THE PARASTROPHINIDAE AND RELATED SPECIES

		American Species.	European Species.	
Helderbergian		*A. verneuili*		
Cayugan			*A. magnifica*	Ludlow
Niagaran	Lockport		*A. deflexa* *Pa. rotunda*	Wenlock
	Clinton	*A. internascens* ? *A. deflexa* *Pa. latiplicata, multiplicata, reversa, ops.* *P. greeni*		Llandovery
Medinan	Albion			
	Richmondian	*Pa. divergens, lenticularis* Earliest Pentamerids		
Cincinnatian			*P. thraivensis* *P. emerita, scotica, youngi*	Bala
Mohawkian	Trenton	*P. hemiplicata, scofieldi* "*A.*" *primigenia*		
	Black River	*C. volborthi*		

A. = *Anastrophia*, *P.* = *Parastrophina*, *Pa.* = *Parastrophinella*, *C.* = *Camerella*.

Genus *Parastrophina* C. Schuchert & C. M. Le Vene, 1929

Schuchert, C., and Le Vene, C. M. New names for Brachiopod homonyms. *Amer. J. Sci.* (5), xvii, 1929, p. 121.

Schuchert, C., and Cooper, G. A. Brachiopod Genera of the Suborders Orthoidea and Pentameroidea. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, 1932, pp. 167–8.

Homonym. *Parastrophia* Hall, J., and Clarke, J. M. *Palaeontology of New York*, viii, pt. 2, 1894, pp. 221–3. (Non *Parastrophia* Follin, 1875.)

Genotype: *Atrypa hemiplicata* Hall, J., *Palaeontology of New York*, i, 1847, p. 144, pl. xxxiii, fig. 10.

Generic description: Small, biconvex to plano-convex, partly costate Parastrophinidae with median dorsal fold and ventral sinus. Outline suboval, the umbones low, approximate. Delthyrium open, largely filled by the incurved dorsal umbo. Well-developed teeth supported on dental-plates compose a delicate spondylium duplex with long median septum. In the dorsal valve the brachial-processes are attached for half their length to high outer-plates which unite to form a cruralium duplex with low supporting septum.

Species

Atrypa hemiplicata J. Hall, 1847.
Parastrophia greeni J. Hall and J. M. Clarke, 1894.
Anastrophia ? hemiplicata var. *rotunda* N. H. Winchell and C. Schuchert, 1893.
Rhynchonella scotica T. Davidson, 1883.
Anastrophia ? scofieldi N. H. Winchell and C. Schuchert, 1893.

Species perhaps to be referred to *Parastrophina:*

Parastrophia emerita F. R. C. Reed, 1917.
Parastrophia thraivensis F. R. C. Reed, 1917.
Parastrophia youngi F. R. C. Reed, 1917.
Parastrophia indica F. R. C. Reed, 1912.
Pentamerus angulosus S. L. Tornquist, 1867.

The name *Parastrophina* was proposed by Schuchert and Le Vene in 1929 to replace *Parastrophia* Hall and Clarke, 1894, a homonym of *Parastrophia* Follin, 1875 (Mollusca). In the original account of the type species *Atrypa hemiplicata* Hall, 1847, the valves were misinterpreted, the larger being considered the ventral. Hall and Clarke's description of the exterior is supplemented by Wilson's account of the variations in the number and form of the plications on fold and sinus. Here it is proposed to describe more particularly the internal structure with reference to the type species *P. hemiplicata* which has been examined in detail. From casts Hall and Clarke inferred the existence of a "spondylium" in each valve, and of the two species referable to *Parastrophina* (*sensu stricto*) of which they give figures the trace of a short septum is shown in both dorsal and ventral valves. Schuchert and Cooper (1932, pp. 167–8) considered the genus to be a synonym of *Camerella*, possessing a duplex spondylium and alate cruralium, an opinion which was revised by Ulrich and Cooper (1938, p. 248). Examination of *Anastrophia ? scofieldi* Winchell and Schuchert, 1893, shows that this species, too, possesses the internal structure of a *Parastrophina*, including the alate cruralium.

Parastrophina hemiplicata (J. Hall), 1847

Text-figs. 3–5

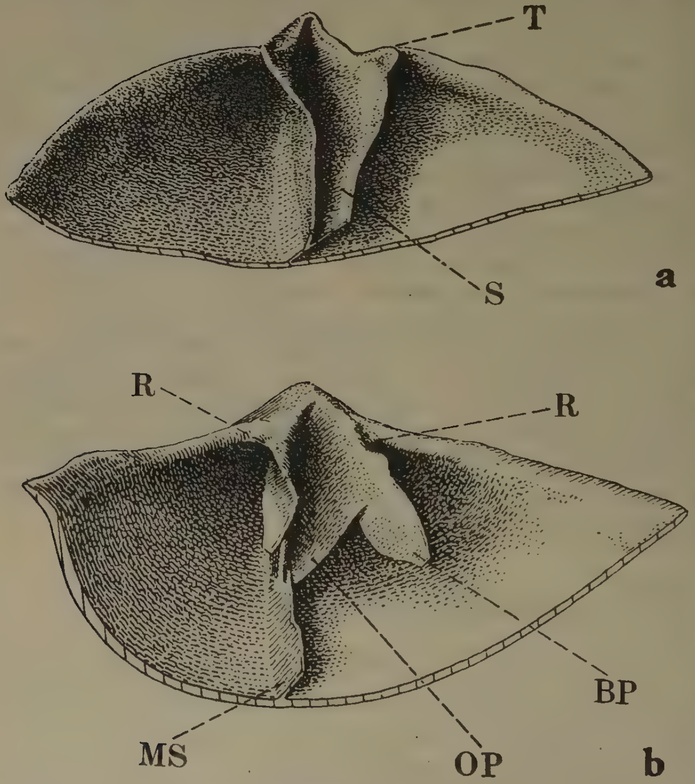
1847 *Atrypa hemiplicata* Hall, J. *Palaeontology of New York*, i, p. 144, pl. xxxiii, figs. 10*a*–*f*.
1894 *Parastrophia hemiplicata* (Hall). Hall, J., & Clarke, J. M. Ibid., viii, pt. 2, pp. 221–2, pl. lxiii, figs. 1–3.
1914 *Parastrophia hemiplicata* (Hall). Wilson, A. E. *Mus. Bull. Geol. Surv. Canada*, ii, pp. 131–140, pl. iv, figs. 1–34.
1932 *Camerella hemiplicata* (Hall). Schuchert, C., & Cooper, G. A. *Mem, Peabody Museum Nat. Hist. Yale*, iv, pt. 1, p. 168, pl. xxv, figs. 3–4, 6. 9–11, 16, 24, 43.

For details of the distribution of this species the references listed by Hall and Clarke (1894, p. 219) and Bassler (1915, p. 945) should be consulted.

Material: British Museum (Nat. Hist.), BB. 1021, B. 12939, Sedgwick Mus., Cambridge, A. 13732–3. {from Trenton Limestone, New York.

Types: Hall's specimens came from the Trenton Limestone at Middleville and other localities in the north-west of New York state.

Diagnosis : Small, oval *Parastrophina*, the dorsal valve is moderately convex, the ventral valve flattened. The rather prominent median dorsal fold and ventral sinus cause a strong, rectangular plication of the anterior margin. The anterior half of the valves is costate, the costae being best developed on fold and sinus. Umbones small ; that in the dorsal valve arches forward closing the delthyrium. In the ventral valve (Text-fig. 3) prominent teeth projecting dorsally from the commissure are developed on high dental-plates. These unite to form a narrow spondylium extending for perhaps a third of the length of the valve and



Text-fig. 3.—*Parastrophina hemiplicata* (J. Hall). (*a*) Dorsal view of a wax model of the posterior portion of a ventral valve ; × 9. S = spondylium ; T = tooth. Constructed from serial transfers of specimen B. 12939, British Museum (Nat. Hist.). (*b*) Antero-ventral view of a wax model of the posterior portion of the dorsal valve of the same specimen ; × 9. BP = brachial-process ; MS = median septum ; OP = outer-plate ; R = socket (cf. Text-figs. 4–5).

supported on a duplex septum which increases in height towards the anterior. In the dorsal valve (Text-figs. 3, 5) short, divergent brachial-processes are attached about the middle of their faces to outer-plates which build a narrow duplex cruralium. The low septum extends beyond the end of the cruralium towards the centre of the valve.

Discussion : The specimens have a gently oval outline, with the umbones rising only a short distance above the hinge-line. The umbones are about equal in height, the dorsal being the more incurved in the adult. The flattened or gently convex ventral profile is only modified anteriorly where the shell is bent forward to close the dorsal fold. The fold and sinus commence about the centre of the valves and become prominent towards the anterior margin. Four rounded costae usually compose the fold and three lie within the sinus with one or two on either side, but study of more abundant material has shown there to be considerable variation in the strength and number of the costae (Wilson, 1914, pp. 132–8). Fine concentric growth-lines are visible when the exterior layers of the shell are preserved.

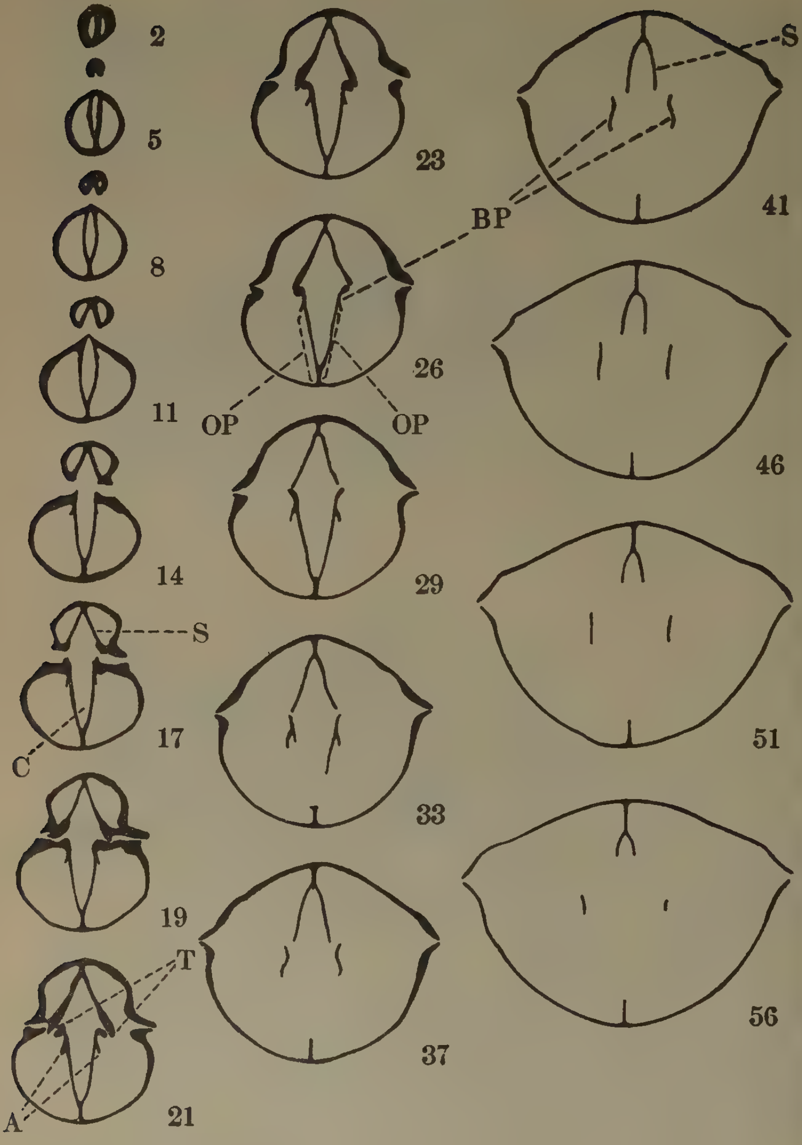
DIMENSIONS OF TYPICAL SPECIMENS

(In millimetres)

Length.	*Breadth.*	*Thickness.*
11·6	13·4	9·4
11·4	13·5	8·4
11·3	11·9	8·7

Internal Characters : No trace was found of any structures constricting the delthyrium ; when the valves are in apposition the opening is largely covered by the dorsal umbo. The delthyrial-margins which are inclined at about 70°, are supported by the dental-plates and from the latter blunt teeth develop at the hinge-line. Sections cut just below the ventral umbo show the spondylium to be almost sessile (Text-fig. 4, transfers 2 to 14), but the dental-plates then unite above the inner surface of the valve to build a duplex spondylium of moderate length. The spondylial cavity narrows below the teeth (Text-fig. 3), the walls approaching each other and as they shorten, the cavity becomes shallower (Text-fig. 4, transfers 29 to 56). The thin supporting septum gradually increases in height as the spondylium curves forward from the floor of the valve.

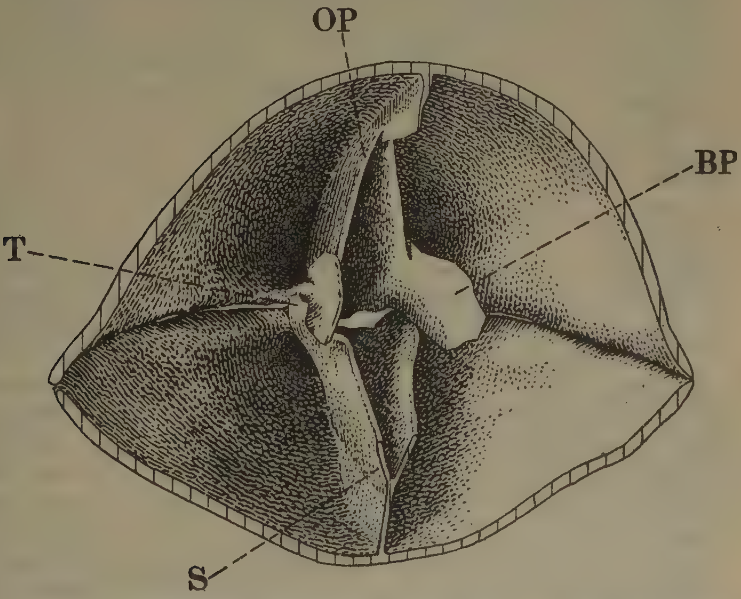
The brachial-processes arise beneath the umbo and curve anteriorly (Text-figs. 3, 5). At first they are convex inwards, but the lower part of each process is almost plane. Where they separate from the valve-margin the outer edges of these plates are somewhat thickened, defining with the margin, the sockets



TEXT-FIG. 4.—*Parastrophina hemiplicata* (J. Hall). Serial transfers at 0·05 mm. intervals from the posterior end of specimen B. 12939, British Museum (Nat. Hist.). Ordovician New York. × 4. Transfers 2–56. A = alae ; BP = brachial-processes ; C = cruralium ; OP = outer-plates ; S = spondylium ; T = teeth.

that receive the teeth of the other valve (Text-figs. 3 and 4, transfers 19 to 21). For half their length these processes are attached to the outer-plates which unite a little above the valve-floor to form a duplex cruralium (Text-figs. 3, 5). The ventral edges of the brachial-processes abut against the sides of the spondylium when the valves are together.

Muscle-scars are not preserved in any of these specimens, but as may be seen from Text-fig. 5 if the normal grouping of scars on either side of the septum in the dorsal valve be assumed, then the muscles must have passed between the brachial-processes.



TEXT-FIG. 5.—*Parastrophina hemiplicata* (J. Hall). Wax model of the posterior portion of a shell, viewed from the anterior. The dorsal valve is uppermost; × 7½. BP = brachial-process; OP = outer-plate; S = spondylium; T = tooth. Constructed from serial transfers of specimen B. 12939, British Museum (Nat. Hist.) (cf. Text-figs. 3–4).

Parastrophina scofieldi (N. H. Winchell and C. Schuchert), 1893

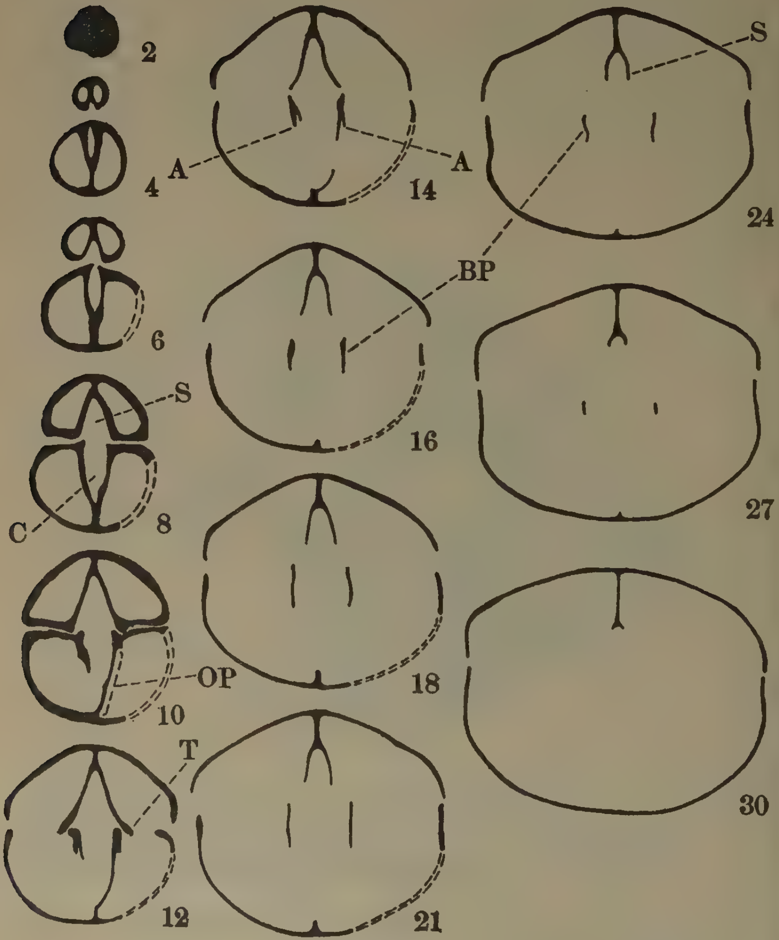
Text-fig. 6

1893 *Anastrophia ? scofieldi* Winchell, N. H., and Schuchert, C. The lower Silurian Brachiopoda of Minnesota. *Minnesota Geol. and Nat. Hist. Surv.*, iii, pt. 1, p. 383, pl. xxx, figs. 24–8.

1932 *Camerella scofieldi* (Winchell and Schuchert). Schuchert, C., and Cooper, G. A. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, pl. xxv, figs. 8, 12–13.

Material : British Museum (Nat. Hist.), B. 78737–8. From Ordovician (Prosser Group), Iowa.

Types : The type specimens came from the Trenton (Prosser), near Cannon Falls, Minnesota.



Text-fig. 6.—*Parastrophina scofieldi* (N. H. Winchell and C. Schuchert). Serial transfers at 0·2 mm. intervals from the posterior end of specimen B. 78737, British Museum (Nat. Hist.). Ordovician Iowa, U.S.A. × 2¼. Transfers 2–30 (slightly restored). A = alae ; BP = brachial-processes ; C = cruralium ; OP = outer-plates ; S = spondylium ; T = tooth.

Diagnosis : Rather large *Parastrophina* with subcircular outline. The umbones are low and incurved. Prominent costae occur on the anterior half of the valves, especially on the fold and sinus. In the ventral valve there is a typical duplex spondylium with a septum which increases in height anteriorly, and continues a short distance beyond the end of the spondylium. The teeth are moderately strong and overlap with the edges of the brachial-processes. The outer-plates of the dorsal valve are short and build a small and rather narrow cruralium supported throughout its length on a duplex septum. The brachial-processes are more widely spaced than in the type species and incline outwards only but slightly from the line of the outer-plates, so that the alae are small. Impressions of muscle-scars are often visible in the dorsal valve on either side of a low median ridge that extends anteriorly from the end of the cruralium.

DIMENSIONS OF TYPICAL SPECIMENS

(In millimetres)

Length.	*Breadth.*	*Thickness.*
18·5	19·6	15·8
16·8	16·9	—

Discussion : The specimen chosen for sectioning (Text-fig. 6), proved to be so silicified that some of the minor internal characters were obscured. The presence of small alae, however, is quite certain and shows this species to possess the structure of a *Parastrophina* rather than of *Camerella*, for although the detailed structure of *C. volborthi*, the type species, does not yet appear to have been described in detail the cardinalia in this genus are not alate (see Ulrich and Cooper, 1938, p. 248). The identification with *Parastrophina* on a basis of the internal structure is confirmed by the external characters. In this species the low and incurved umbones, the tendency to a transverse outline, the greatest width of the shell being attained rather less than half-way to the anterior margin, and the gentle convexity of the ventral valve all show agreement with the typical *Parastrophina* rather than with *Camerella*.

From *P. hemiplicata* this species differs in size and outline and in internal structures there is apparently no tendency for either spondylium or cruralium to be sessile posteriorly. The small, inconspicuous alae have already been noted.

Hall and Clarke referred to *Parastrophina* a number of new species, as well as *Rhynchonella scotica* Davidson. Most of these are more probably examples of *Parastrophinella* for they show the sessile cruralium and extremely convex dorsal valve of that genus—but to judge from Hall and Clarke's figures, *Parastrophia greeni* is a true *Parastrophina.* In this species the spondylium and cruralium are supported on septa which are less than half the length of the valve while the outline is rather more rounded than in the type species. *Parastrophina scotica* (Dav.) is small and almost circular in outline, with the two valves of approximately the same convexity, the ventral being slightly the higher. Both Davidson (1883, pl. xi, fig. 26) and Reed (1917, p. 929, pl. xxii, fig. 43) recognized the median septum in each valve. The three small species *Parastrophia emerita*, *thraivensis*, and *youngi* described by Reed from Girvan, are probably to be referred to *Parastrophina* but study of the few available specimens hardly permits of certainty. Reed's figures show *P. youngi* to be sub-rectangular in outline with a globose dorsal valve in which the cruralium approaches the sessile condition posteriorly, an approximation to the structure of *Parastrophinella.*

Anastrophia primigenia Bradley, 1930, from the Trenton of Missouri and Illinois may also be mentioned here. The internal structures have not been described, but to judge from figures the species is more correctly to be referred to *Camerella* or *Parastrophina*, a conclusion which might be suspected from the stratigraphical distribution of these genera (see table, p. 376).

Parastrophina hemiplicata var. Reed (1932, p. 140, pl. xxi, figs. 7–7*a*) does not appear from the published figures to agree with the type species either in outline or in the convexity of the valves, while the affinities of *P. simplex* Reed (1932, p. 144, pl. xxii, figs. 11–11*a*), of which only one specimen is known, are also uncertain. The sharply angular posterior margin hardly resembles *Parastrophina.*

Genus *Parastrophinella* C. Schuchert & G. A. Cooper, 1931

Schuchert, C., and Cooper, G. A. Synopsis of the Brachiopod Genera of the Suborders Orthoidea and Pentameroidea. *Amer. J. Sci.*, (5), xxii, 1931, p. 248, and idem. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, 1932, p. 169.

Genoholotype : *Pentamerus reversus* Billings, E. *Geol. Surv. Canada*, Rept. of Progress for 1856 (1857), pp. 295–6.

Generic description : Moderately biconvex to strongly biconvex anteriorly costate Parastrophinidae with the reverse convexity emphasized. The dorsal valve is always the higher and may approach a hemispherical shape. On the anterior half of the shell a low dorsal fold and prominent ventral sinus. Teeth small, the edges of the spondylium project slightly from the commissure at the lower corners of the delthyrium. The dental-plates build a small spondylium which is sessile below the umbo, but curves forward anteriorly, being raised on a low septum. In the dorsal valve the cardinalia consist of sub-parallel brachial-processes supported on rather high outer plates which compose a sessile cruralium.

Species

Pentamerus reversus E. Billings, 1857.
Atrypa rotunda J. de C. Sowerby, 1839.
Camerella lenticularis E. Billings, 1866.

Compare also :—

Parastrophia divergens J. Hall and J. M. Clarke, 1894.
Parastrophia multiplicata J. Hall and J. M. Clarke, 1894.
Parastrophia latiplicata J. Hall and J. M. Clarke, 1894.
Camerella ops E. Billings, 1865. (? Synonym of *P. reversus*).

Parastrophinella is very closely related to *Parastrophina* from which it differs in having the reverse convexity more strongly marked causing greater inequality between the valves. In the ventral valve there is a stronger tendency for the spondylium to be sessile than in either *Parastrophina* or *Anastrophia* while in the dorsal valve the cardinalia converge only on approaching the valve-floor. It may be noted that casts of the type species and even isolated valves, or models are rather deceptive, for growth-lines of the shell revealed in transfer preparations show a low, median septum to be often present but embedded in secondary shell thickening. This has led Schuchert and Cooper to describe the outer-plates as discrete and not forming a cruralium duplex (1932, p. 169).

Parastrophinella reversa (E. Billings), 1857

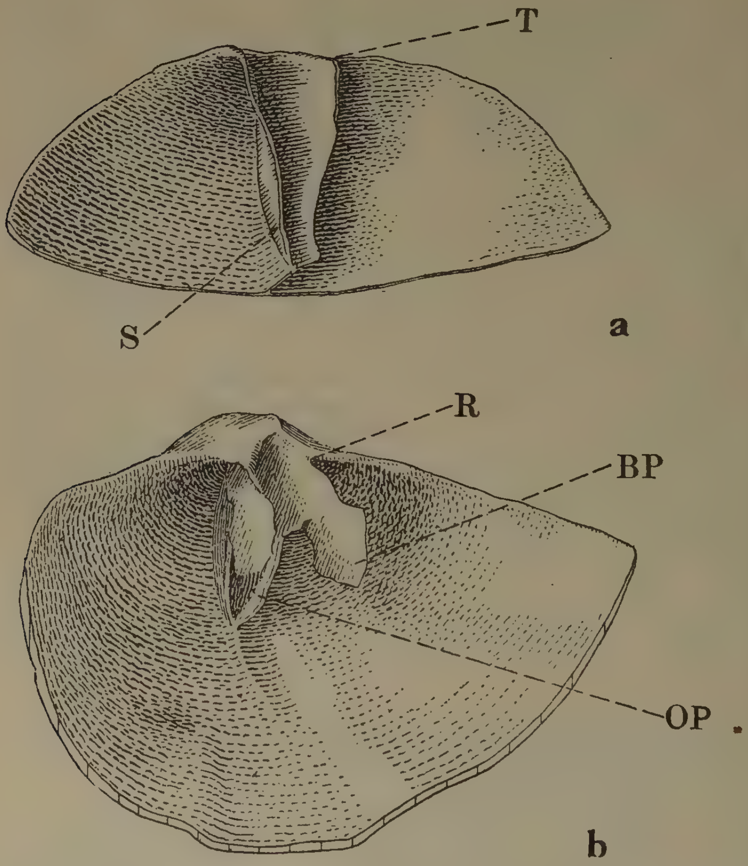
Text-figs. 7–9

1857 *Pentamerus reversus* Billings, E. *Geol. Surv. Canada*, Rept. of Progress for 1856, pp. 295–6 and idem. *Canadian Journal*, iv, p. 316, 1859.
1894 *Parastrophia reversa* (Billings). Hall, J., and Clarke, J. M. Palaeontology of New York, viii, pt. 2, pl. lxiii, figs. 8–13.
1914 *Parastrophia reversa* (Billings). Wilson, A. E. *Mus. Bull. Geol. Surv. Canada*, ii, p. 132, pl. iv, figs. 35–9.
1932 *Parastrophinella reversa* (Billings). Schuchert, C., and Cooper, G. A. Brachiopod Genera of the Suborders Orthoidea and Pentameroidea. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, p. 169, pl. xxix, fig. 7.

Material : British Museum (Nat. Hist.) BB. 987–1018, BB. 1051, B. 12946–9, B. 12596–8, B. 5618. } From Anticosti Is., Canada.
Sedgwick Museum, Cambridge, A. 13734.

Types : Billings' specimens came from a Clinton horizon (Silurian) at Junction Cliff, Anticosti Island.

Diagnosis : Typical large, strongly biconvex *Parastrophinella*, with the umbones much incurved and almost touching : the ventral umbo is often slightly resorbed. Usually a prominent, low median fold and deep sinus, which are expressed at the anterior margin as a deep plication with sloping sides. Rather rounded costae occur especially on the anterior half of the shell. From three to six commonly compose the fold while one fewer lies within the sinus. The spondylium (Text-figs. 7–9) is small



Text-fig. 7.—*Parastrophinella reversa* (E. Billings). (*a*) Dorsal view of a wax model of the posterior portion of a ventral valve. × 4½. S = spondylium ; T = tooth. Constructed from serial transfers of specimen BB. 1012, British Museum (Nat. Hist.). (*b*) Antero-ventral view of a wax model of the posterior portion of the dorsal valve of the same specimen ; × 4½. BP = brachial-process ; OP = outer-plate ; R = socket (cf. Text-figs. 8–9).

and sessile for the posterior half of its length, anteriorly it is supported on a thin duplex septum. The outer-plates are high owing to the convexity of the dorsal valve, but extend hardly below the level of the hinge-line ; they converge on approaching the valve-floor to form a sessile cruralium (Text-fig. 7) which may be slightly elevated above the valve-surface at its anterior end. The muscle-scars are grouped centrally on the inner valve-surface at the base of the cruralium.

DIMENSIONS OF TYPICAL SPECIMENS

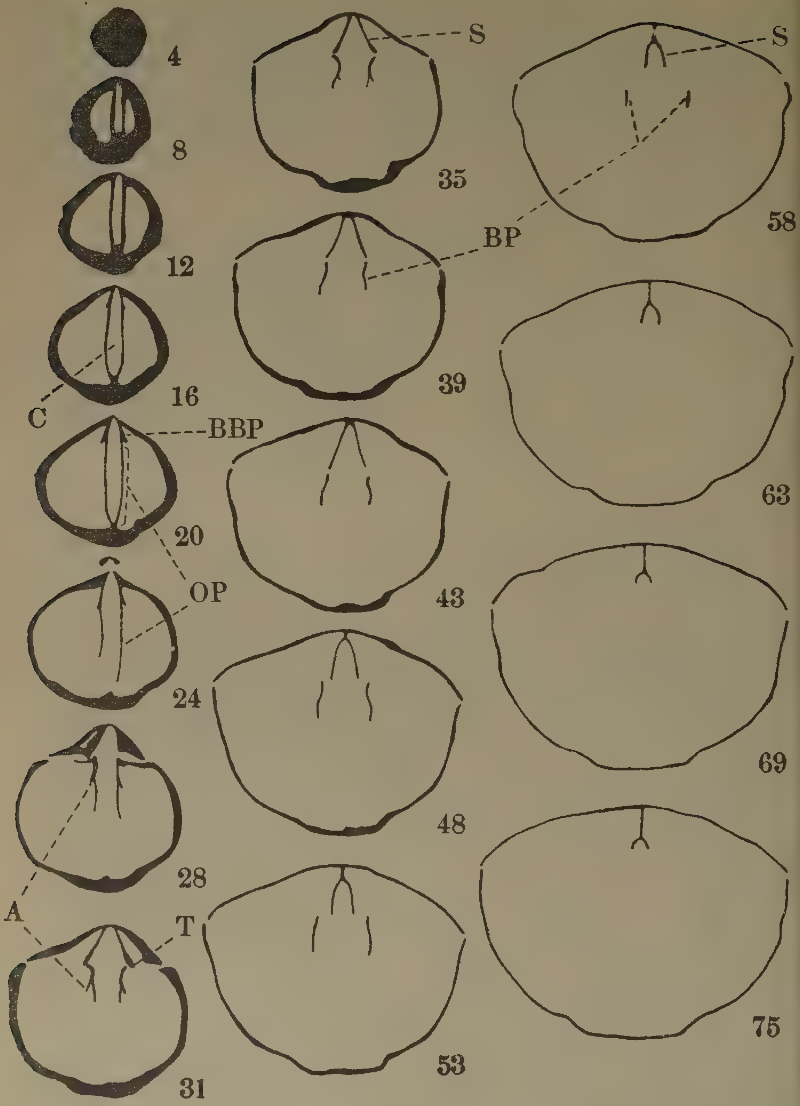
(In millimetres)

Length.	*Breadth.*	*Thickness.*
19·2	25·4	13·8
22·5	26·5	18·6
19·6	23·8	16·0
18·8	24·3	14·6
20·5	26·2	15·3
19·6	26·3	15·1

Discussion : Billings (1859, p. 316) subsequently considered this species to be only a variety of *Parastrophina hemiplicata* which is similar in proportions and outline. *P. hemiplicata*, however, attains to but one-third of the dimensions of *P. reversa* and never develops the very convex dorsal valve and strong incurving of the umbones of this species. The variations in the costae have been compared by Wilson (1914, pp. 138–140) with the similar range in *P. hemiplicata*. The costae usually arise rather less than halfway down the valves and increase in size towards the anterior margin, where between ten and fifteen may be counted in different specimens. The fold and sinus commence fairly high on the valves and are strongly developed at the margin, occupying between one-quarter and one-third of the valve surface.

In the interior the reduction of the teeth is marked—the two valves must have been held together largely by the muscles. The structures in the dorsal valve are intermediate between *Parastrophina* and *Anastrophia* : the brachial-processes are slightly curved as in *Anastrophia*, while the outer-plates remain parallel for the greater part of their height, converging on the floor of the valve (Text-figs. 7–9 ; cf. *Parastrophina*, Text-fig. 4). In these specimens no septum continues anteriorly from the end of the cruralium.

Camerella ops Billings (1865, p. 148, fig. 128 ; Schuchert and Cooper, 1932, pl. xxv, figs. 23, 25–6), to judge from the original figures, appears to be very close to *Parastrophinella reversa* of which it may be but a young specimen. Of external characters it seems to differ only in the valves being less completely costate.



Text-fig. 8.—*Parastrophinella reversa* (E. Billings). Serial transfers at 0·1 mm. intervals from the posterior end of specimen BB. 1012, British Museum (Nat. Hist.). Silurian Anticosti Is. × 2. Transfers 4–75. A = alae; BBP = bases of the brachial-processes; BP = brachial-processes; C = cruralium; OP = outer-plates; S = spondylium; T = tooth.

Parastrophinella rotunda (J. de C. Sowerby), 1839

Text-fig. 10

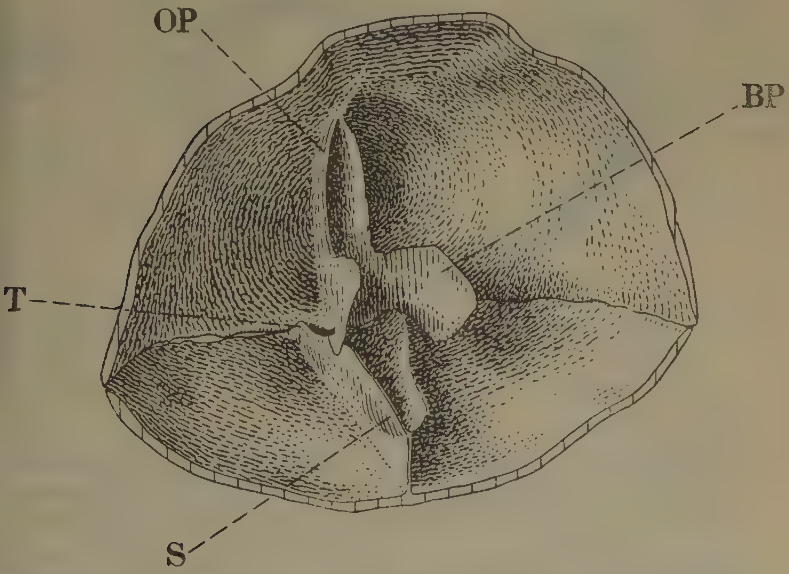
1839 *Atrypa rotunda* Sowerby, J. de C., in Murchison's *Silurian System*, p. 629, pl. xiii, fig. 7.

1867 *Pentamerus rotundus* (J. de C. Sowerby). Davidson, T., British Fossil Brachiopoda. *Palaeontogr. Soc. Lond.* [*Monogr.*], iii, pt. vii, pp. 150–1, pl. xv, figs. 9–12. Idem, v, pt. ii (1883), p. 163, pl. ix, figs. 6–9.

1917 *Parastrophia rotunda* (J. de C. Sowerby). Reed, F. R. C. The Ordovician and Silurian Brachiopoda of the Girvan district. *Trans. Roy. Soc. Edinb.*, li, pt. 4, p. 928, pl. xxii, figs. 35–41.

Material : British Museum (Nat. Hist.), B. 72680, } From the Penkill
B. 72677– } Group, Girvan.

Type : Sowerby's specimen came from the Wenlock Limestone of Wenlock Edge.



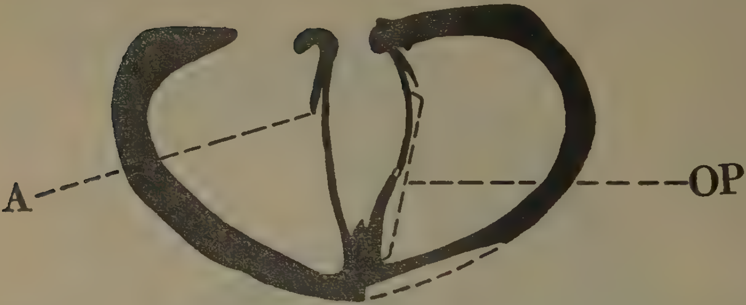
Text-fig. 9.—*Parastrophinella reversa* (E. Billings). Wax model of the posterior portion of a shell, viewed from the anterior. The dorsal valve is uppermost ; × 4½. BP = brachial-process ; OP = outer-plate ; S = spondylium ; T = tooth. Constructed from serial transfers of specimen BB. 1012, British Museum (Nat. Hist.) (cf. Text-figs. 7–8)

Diagnosis : Large *Parastrophinella* ; the dorsal valve is moderately or strongly convex, the ventral valve flattened. A low, broad fold is present at the margin of the dorsal valve with a corresponding shallow ventral sinus, both of which may be folded anteriorly into broad, irregular costae. In the ventral valve the dental-plates form a duplex spondylium, sometimes sessile posteriorly, which attains to about half the length of the shell. In the dorsal valve (Text-fig. 10) the brachial-processes have their ventral edges considerably thickened where they abut against the spondylium. The alae are long. The outer-plates form a sessile cruralium which may be elevated anteriorly on a low, duplex septum.

Dimensions of Typical Specimens

(In millimetres)

Length.	*Breadth.*
24·7	27·6
21·0	28·4
24·2	30·1
20·1	26·5



Text-fig. 10.—*Parastrophinella rotunda* (J. de C. Sowerby). Section through the posterior end of a dorsal valve. Specimen B. 72679, British Museum (Nat. Hist.). Penkill group, Girvan. × 6. A = ala; OP = outer-plate.

Davidson's figures (1867, pl. xv, figs. 9–11) show the ventral valve to be rather higher than the dorsal and suggest that the cruralium is usually sessile, while the normal variation encountered in the Girvan district has been illustrated by Reed (1917, pl. xxii, figs. 35–41). In casts, the outline of the adductor muscle-scars may be visible near the centre of the valve-surface on either side of the median septum (B. 72680; cf. Reed, op. cit., fig. 41, which shows a dorsal valve, not ventral as stated).

Parastrophinella lenticularis (E. Billings), 1866

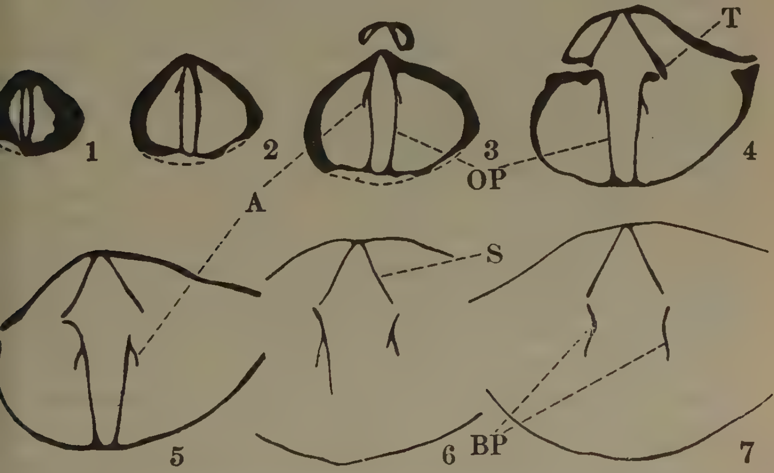
Text-fig. 11

1866 *Camerella lenticularis* Billings, E. Catalogue of the Silurian fossils of the Island of Anticosti (*Geol. Surv. Canada*), p. 45.

Material: British Museum (Nat. Hist.), B. 77573–77577. B. 76494–504. Sedgwick Museum, Cambridge, A. 13736–7. } From Junction Cliff, Anticosti Is.

Types: Billings' specimens came from a Richmond (English Head) horizon at Reef Point, Anticosti Is.

Diagnosis: Small, rather transverse, gently biconvex *Parastrophinella* with shallow, more or less undefined median fold and sinus expressed as a rounded curve in the anterior margin. The surface of the valves is smooth, often becoming gently costate towards the margin. Profile lenticular, the dorsal valve is slightly the more convex. The umbones are small and usually touching. In the ventral valve the slender spondylium is sessile for most of its length but sometimes raised on a septum anteriorly (Text-fig. 11). Small teeth project from the lower corners of the delthyrium. The strongly alate cardinalia consist of brachial-processes and long outer-plates, which converge slightly to form a sessile cruralium.



TEXT-FIG. 11.—*Parastrophinella lenticularis* (E. Billings). Seven transfers from the posterior end of specimen B. 77575, British Museum (Nat. Hist.). Silurian Anticosti Is. × 6. A = alae; BP = brachial-processes; OP = outer-plates; S = spondylium; T = tooth.

DIMENSIONS OF TYPICAL SPECIMENS
(In millimetres)

Length.	*Breadth.*	*Thickness.*
13·1	16·2	6·2
15·7	19·2	9·3
13·9	17·9	7·8
13·2	16·0	7·1
14·2	17·0	8·2
16·4	20·6	8·3

Discussion: *P. lenticularis* differs from the other species of *Parastrophinella* in its small size and lenticular profile. The marked convexity of the valves so typical of the genus, is not found in this species, and its identification as a *Parastrophinella* rather than *Parastrophina* rests largely on internal structure. The fold and sinus are rather inconspicuous though nearly always present, while the costae may commence near the centre of the valves with as many as ten at the anterior margin, or the shell-surface may be almost entirely smooth.

The spondylium closely resembles that structure in *P. reversa* but shows an even stronger tendency to be sessile, being elevated on a septum if at all only at the extreme lower end (Text-fig. 11). In the dorsal valve the cardinalia differ in shape from the corresponding structure in the type species; the outer-plates are longer and incline together more gradually, while the alae are usually more distinctly developed. Sometimes the outer-plates remain almost entirely separate so that the dorsal structures may be more correctly described as a " cruralium discretum " rather than a " sessile cruralium ".

Genus *Anastrophia* J. Hall, 1867

Hall, J. *20th Rept. New York State Cabinet of Nat. Hist.*, 1867, p. 162.
Hall, J. *Palaeontology of New York*, iv, 1867, pp. 373–4.
Hall, J., and Clarke, J. M. *Palaeontology of New York*, viii, pt. 2, 1894, pp. 224–5.
Schuchert, C., and Cooper, G. A. Brachiopod Genera of the Suborders Orthoidea and Pentameroidea. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, 1932, pp. 169–170.
Homonym: *Brachymerus* Shaler, N. S. *Bull. Museum Comp. Zool. Harvard*, i, 1865, p. 69. (Non *Brachymerus* Dahlbom, 1845.)
Genolectotype: (Chosen by Hall and Clarke, 1894) *Pentamerus verneuili* Hall, J. *10th Rept. New York State Cabinet of Nat. Hist.*, 1857, p. 104, figs. 1–2.

Generic description: Rather strongly biconvex wholly costate, transverse Parastrophinidae, with a suboval or polygonal outline. The dorsal valve is considerably the larger and more convex, with a low fold seen only towards the anterior. The ventral sinus usually commences above the centre of the valve. The dorsal umbo is prominent and arched forward in the adult to close the delthyrium The ventral umbo is low and acute; the delthyrium may be bordered on each side by a narrow curved area.

In the anterior of the ventral valve stout teeth project from the corners of the delthyrium. The dental-plates unite to form a rather narrow spondylium supported anteriorly on a low duplex septum (Text-fig. 13). In the dorsal valve the alate cardinalia consist of gently curving brachial-processes, attached to short outer-plates, which remain parallel or nearly so and rarely unite to form a cruralium. The ventral edge of each brachial-process is curved outwards and thickened where it joins the valve-wall, forming a buttress for articulation with the corresponding tooth. Muscle-scars are grouped on the inner valve-surface at the lower end of the outer-plates.

Species

Atrypa verneuili J. Hall, 1857.
Atrypa internascens J. Hall, 1879.
Terebratula deflexa J. de C. Sowerby, 1839.
Anastrophia magnifica R. Kozlowski, 1927.
Pentamerus ? podolicus P. Wieniukow, 1899 (teste Kozlowski, 1929).

Compare also :—

Terebratula brevirostris J. de C. Sowerby, 1839.
Terebratula sphaerica J. de C. Sowerby, 1839.
Terebratula interplicata J. de C. Sowerby, 1839.

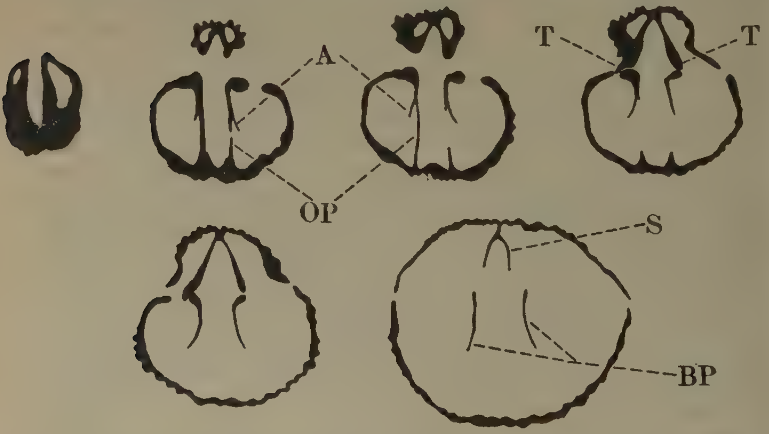
Discussion : Hall (1867) proposed the genus *Anastrophia* to include the three species "*Pentamerus*" *verneuili*, *reversus*, and *interplicata*, of which the first two had been referred by Shaler (1865, p. 69) to his genus *Brachymerus*. This name is a homonym of *Brachymerus* Dahlbom, 1845. Hall and Clarke (1894, p 224) chose as type *Anastrophia verneuili*, a species from the Lower Devonian (Lower Helderberg) of New York. To the same genus there also belongs *Terebratula deflexa* J. de C. Sowerby, 1839, with which *T. sphaerica*, *T. interplicata*, and *T. brevirostris*, described by Sowerby at the same time, have often been considered synonymous.

The completely costate surface of *Anastrophia* distinguishes it at once from other Parastrophinidae. The costae begin near the umbo and increase in size anteriorly, where a few new folds may appear in the interspaces. As in *Parastrophinella* the reverse convexity is well marked in this genus, especially so in the type species, where the dorsal valve arches forward from the commissure (Text-fig. 13) to cover not only the delthyrium but also part of the cardinal-area. In this condition there can hardly have been a functional pedicle, though Schuchert and Cooper (1932, p. 170) considered that the abrasion sometimes present about the umbones might have been caused by the pedicle. *A. verneuili* (Hall) and *A. magnifica* Koz. display the normal transverse outline ; the latter has also a tendency to rather sharp cardinal margins. The cardinal-area is best seen in the type species, in *A. deflexa* it is often absent or hidden by the dorsal umbo. Posteriorly the dental-plates may join only at the valve-floor, but the spondylium is supported further forwards on a low septum. In the dorsal valve the brachial-processes arise beneath the umbo and curve downwards remaining almost parallel. They are attached to the outer-plates near their ventral edges, leaving small, slender alae. The parallel outer-plates seldom extend far below the level of the hinge line, but their apparent length as revealed by serial sections such as Text-figs. 14 and 16 will depend on the extent of incurving of the dorsal valve. In *A. magnifica*, Kozlowski (1929, p. 141, fig. 42) has described closely-fitting teeth and sockets, a rather more complicated dentition than is known in other species of this genus.

Anastrophia verneuili (J. Hall), 1857

Text-fig. 12

1857 *Atrypa verneuili* Hall, J. *10th Ann. Rept. N.Y. State Cabinet of Nat. Hist.*, p. 104, figs. 1–2.
1859 *Pentamerus verneuili* Hall, J. *Palaeontology of New York*, iii, pp. 260–2, pl. xlviii, figs. 1*a–y*. [Text, 1859, plates, 1861.]
1894 *Anastrophia verneuili* (J. Hall). Hall, J., and Clarke, J. M. *Palaeontology of New York*, viii, pt. 2, p. 224, pl. lxiii, figs. 31–8.
1932 *Anastrophia verneuili* (J. Hall). Schuchert, C., and Cooper, G. A. *Mem. Peabody Museum Nat. Hist. Yale*, iv, pt. 1, p. 170, pl. xxv, figs. 14–15, 19, 33–6, 38–9, 41–2.
Material : British Museum (Nat. Hist.), BB. 1019–1020. B. 12877, from the Lower Helderberg of New York.
Types : Hall's specimens came from the Lower Helderberg group, Helderberg Mnts., New York.



Text-fig. 12.—*Anastrophia verneuili* (J. Hall). Six transfers from the posterior end of specimen BB. 1020, British Museum (Nat. Hist.). Lower Devonian, New York. × 2. A = alae ; BP = brachial-processes ; OP = outer-plates ; S = spondylium ; T = teeth.

Diagnosis : Largely as for the genus. The umbones are conspicuous, the dorsal valve is often considerably higher than the ventral and curved forward from the hinge-line. The median fold and sinus are rather clearly defined and produce a rectangular plication of the anterior margin. A narrow, curved area is often present on either side of the delthyrium. In the ventral valve the outer-plates are slightly divergent (Text-fig. 12). The delicate brachial-processes are long, extending nearly as far anteriorly as the end of the spondylium.

DIMENSIONS OF TYPICAL SPECIMENS

(In millimetres)

Length.	*Breadth.*	*Thickness.*
17·6	21·3	15·5
17·3	21·5	14·7
17·1	21·2	15·7

Discussion : In size this species lies between *Anastrophia deflexa* and Kozlowski's *A. magnifica* which is considerably the larger. The limits of the fold and sinus are more clearly defined than in other species and the characteristic rectangular folding of the margin may be easily distinguished from the rounded fold of *A. deflexa*. Commonly in the adult six or seven costae are present on the fold and one fewer on the sinus while from twenty-seven to thirty-two occur round the whole of the anterior margin. The incurving of the dorsal umbo may be so great as to cause abrasion or resorption of the valves, producing the appearance of a false foramen as figured by Hall and Clarke (1894, p. 224, pl. lxiii, fig. 38).

Even at the level of the hinge the spondylium is hardly raised above the valve-floor owing to the very low septum in this species. The brachial-processes are broad, their ventral edges are considerably thickened where they abut against the teeth ; the delicate alar extensions typical of this species are well seen in Text-fig. 12. In the specimens that have been sectioned the outer-plates diverge slightly as they approach the valve-floor, but they are hardly ever as long as in the case illustrated by Hall and Clarke (1894, pl. lxiii, fig. 38). None of the present individuals have been found to possess the alate dental-plates shown in Hall's figures in his first detailed description of the species (1859 p. 261, pl. xlviii, figs. 1*u*, *x*), but these perhaps represent the alate cardinalia of the dorsal valve rather than the ventral interior.

Anastrophia deflexa (J. de C. Sowerby), 1839

Text-figs. 13–16

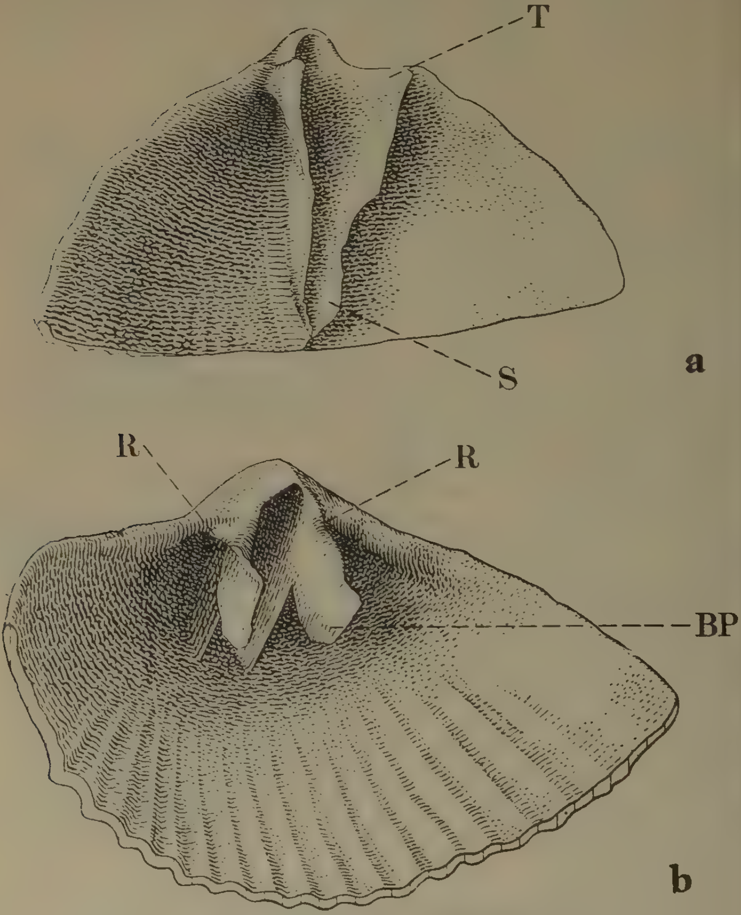
1839 *Terebratula deflexa* Sowerby, J. de C., in Murchison's *Silurian System*, p. 625, pl. xii, fig. 14.

1869 *Rhynchonella deflexa* (J. de C. Sowerby). Davidson, T. British Fossil Brachiopoda. *Palaeontogr. Soc. Lond.* [*Monogr.*], iii, pt. vii, pp. 178–180, pl. xxii, figs. 24–7. Idem., v, pt. ii (1883), p. 156, pl. x, fig. 23 (?).

1932 *Anastrophia deflexa* (J. de C. Sowerby). Schuchert, C., and Cooper, G. A. *Mem. Peabody Mus. Nat. Hist. Yale*, iv, pt. 1, pl. xxv, fig. 40.

Material : British Museum (Nat. Hist.), B. 12956, BB. 1022 } from Gotland,
Sedgwick Mus., Cambridge, A. 13739–79. { from Wenlock Limestone of Dudley, Walsall, etc.

Types : Sowerby's specimens came from the Wenlock Limestone of Wenlock Edge.



Text-fig. 13.—*Anastrophia deflexa* (J. de C. Sowerby). (*a*) Dorsal view of a wax model of the posterior portion of a ventral valve ; × 6. S = spondylium ; T = tooth. Constructed from serial transfers of specimen A. 13768, Sedgwick Museum, Cambridge. (*b*) Antero-ventral view of a wax model of the posterior portion of the dorsal valve of the same specimen ; × 6. BP = brachial-process ; R = socket (cf. Text-figs. 14–15).

Diagnosis: Moderately biconvex, oval *Anastrophia*. Umbones approximate. The delthyrium is small and the dorsal umbo seldom curved far forward from the plane of junction of the valves. The median fold and sinus are inconspicuous, being expressed by a gentle arching of the anterior margin. The ventral area is small.

In the interior the brachial-processes arise just behind the umbo and lie close to the edges of the spondylium. There are very small alar extensions where the processes diverge from the short, parallel outer-plates (Text-figs. 13–14). Paired adductor-scars are often visible on the surface of the dorsal valve below the outer-plates.

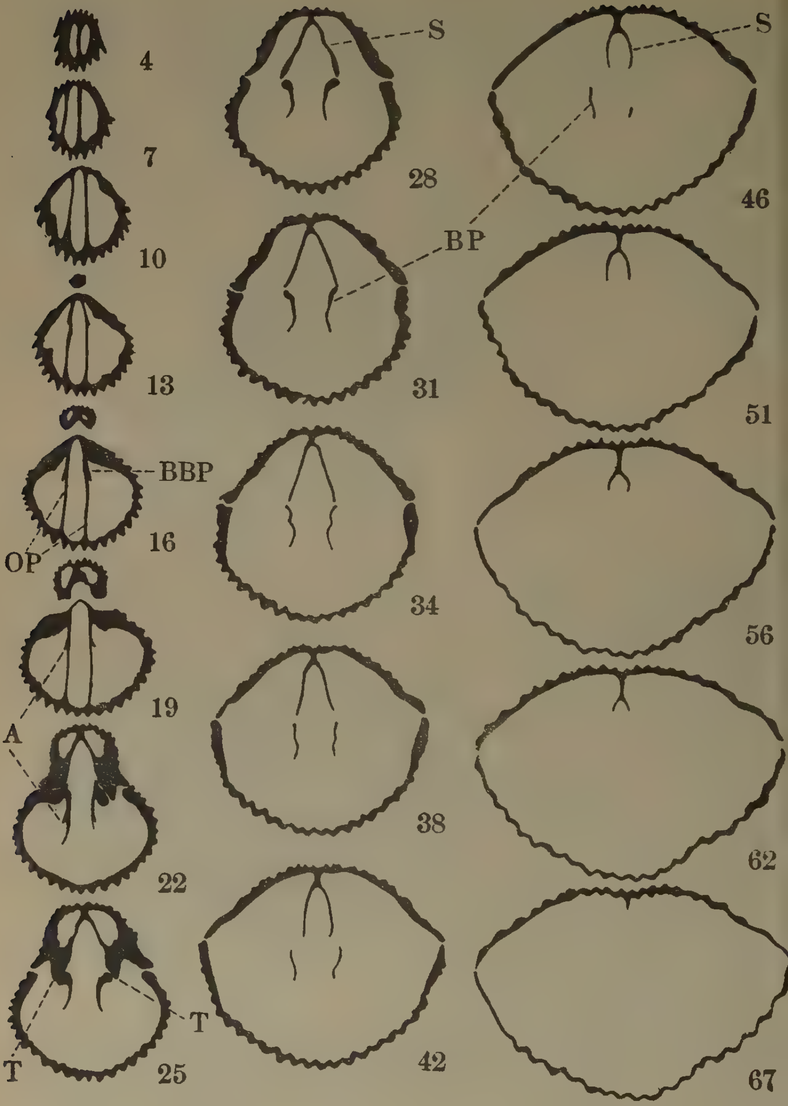
DIMENSIONS OF TYPICAL SPECIMENS

(In millimetres)

Length.	*Breadth.*	*Thickness.*
13·9	16·7	11·0
12·4	16·3	11·8
14·6	19·3	10·0
13·9	16·5	12·3
11·4	14·7	11·0
13·9	16·4	10·3

Discussion: *A. deflexa* is less transverse and with lower umbones than the type species. Though the dorsal umbo may be much incurved (Text-fig. 13*b*) it does not lie below the ventral as is commonly the case in *A. verneuili*. In many specimens there is no interruption of the normal convexity of the dorsal valve that can be recognized as a fold; the shallow sinus near the ventral anterior margin is more persistent, though indistinctly defined. The whole of the exterior is covered with angular costae, of which from four to seven are usually involved in the fold and sinus, and in normal adult specimens twenty-five may be counted round the anterior margin. These costae are corrugations of the valve-wall so that the majority are equally visible on both inner and outer valve-surfaces (Text-figs. 13, 15). Concentric growth-lines may be developed over the entire surface of both valves.

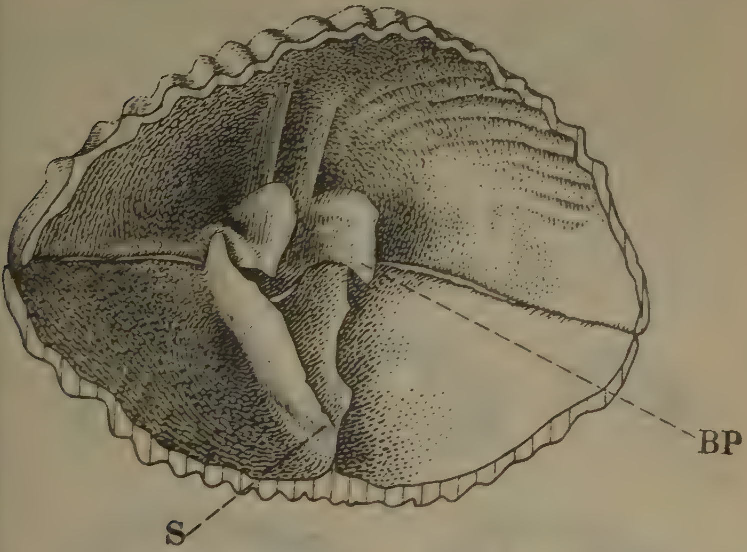
The delthyrium is rather narrow with an angle of some 60° or 70° and at the antero-dorsal corners unusually strong teeth project from the hinge-line (Text-figs. 13–14). The spondylium extends for about one-third of the distance to the anterior margin: it may be sessile for a short distance below the umbo, but is raised anteriorly on a low septum which continues as a slight ridge to the centre of the valve (Text-figs. 13, 15). At the level of the hinge-line the cross-section of the



Text-fig. 14.—*Anastrophia deflexa* (J. de C. Sowerby). Serial transfers at 0·1 mm. intervals from the posterior end of specimen A. 13768, Sedgwick Museum, Cambridge. Wenlock Limestone, Dudley. × 2½. Transfers 4–67. A = alae; BBP = bases of the brachial-processes; BP = brachial-processes; OP = outer-plates; S = spondylium; T = teeth.

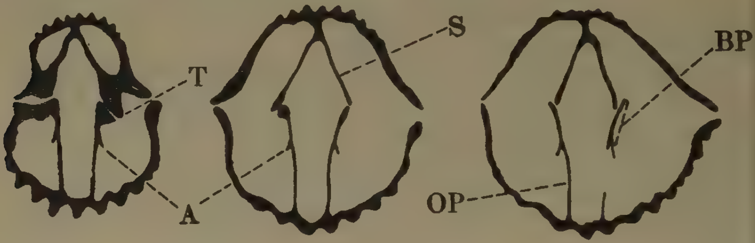
spondylium is an equilateral triangle, but towards the anterior the walls decrease in height and become parallel-sided (Text-fig. 14). Schuchert and Cooper (1932, pl. xxv, fig. 40) record short alae at the mid-points of the sides of the spondylium, seemingly an accidental feature for it is not found in any of the present specimens.

The ventral edges of the brachial-processes are thickened and curved laterally where they separate from the hinge-line. These expansions, corresponding to the "fulcral plates" of Schuchert and Cooper (1932, pp. 164, 169), form supports for the inner faces of the teeth which abut against them when the valves are in the position of life (Text-figs. 14–15). The alae are short, never displaying the long extensions present in *A. verneuili*, while the outer-plates remain parallel or slightly convergent throughout their length.

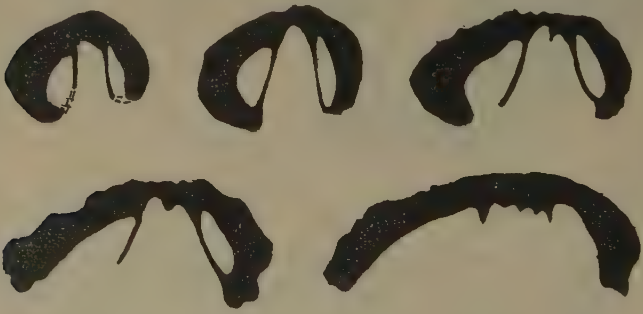


TEXT-FIG. 15.—*Anastrophia deflexa* (J. de C. Sowerby). Wax model of the posterior portion of a shell, viewed from the anterior. The dorsal valve is uppermost; × 6. BP = brachial-process; S = spondylium. Constructed from serial transfers of specimen A. 13768, Sedgwick Museum, Cambridge (cf. Text-figs. 13–14).

The genus *Metacamerella* Reed (1917, p. 934) was placed by Schuchert and Cooper in their family Camerellidae (1932, p. 170) close to *Anastrophia*. Suitable material has not been available for a complete re-examination of this genus, but it can hardly be included within the family Parastrophinidae as now defined. Sections (Text-fig. 17) through the posterior end of a dorsal valve—to follow the usually adopted orientation of the shell—show two plates from which the long recurved "crura" described by Reed may perhaps continue in complete specimens. In no examples do the plates appear to unite to form a cruralium, nor can any division into brachial-processes and outer-plates be observed.



TEXT-FIG. 16.—*Anastrophia deflexa* (J. de C. Sowerby). Three transfers from the posterior end of specimen A. 13767, Sedgwick Museum, Cambridge. "Wenlock Limestone," Dudley. × 4½. A = alae; BP = brachial-process; OP = outer-plate; S = spondylium; T = tooth.



TEXT-FIG. 17.—*Metacamerella balclatchiensis* (T. Davidson). Five transfers from the posterior end of specimen B. 73128, British Museum (Nat. Hist.). Balclatchie Beds, Girvan. × 4.

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REVIEWS

OUTLINES OF STRUCTURAL GEOLOGY. By E. SHERBON HILLS. pp. vii + 172, with 4 plates and 105 text illustrations. Methuen. 6*s*. 6*d*.

Dr. Sherbon Hills is to be congratulated on the production of this book, which on account of the classification of the subject matter and clarity of presentation will no doubt be warmly welcomed by students of geology, for whom it is primarily intended ; whilst the excellent bibliography of recent literature on the subject will also make a strong appeal to geologists of maturer age.

The subject matter is for the most part thoroughly up-to-date ; the author has aimed at presenting " an outline of those sections of structural geology that are most likely to find practical application in the field or in the laboratory ". In this he has been successful, and though undoubtedly there are limitations to the extent to which laboratory experiments can reproduce field conditions, it is probable that his experiments will at any rate give students some idea of the nature of the processes involved and the reactions to them.

In the chapter on non-diastrophic structures the author wisely notes that though very useful, graded bedding is not an infallible guide to the order of superposition of rocks ; in connection with his section on subaqueous slumping and gliding it may be hoped that the author will, in a later edition, find a place for a reference to Bullard's recent work on that subject which was published too late to be included.

One of the most striking chapters deals with major crustal structures, though here in connection with " mobile belts " one misses any reference to the work of Meinesz and his colleagues, all the more since there is a reference to Bullard's work on the African Rift Valley which belongs to the second type of his regional structures " Resistant Blocks ".

In the section dealing with the minor structures of folded rocks, the part dealing with joints attracts attention by reason of its clarity, and the excellence of the illustrations : this subject has been too rarely dealt with in adequate fashion in a students' text-book. In the chapter on faults the author adopts a nomenclature which has as its chief merit that the student must realize the effect of each fault on the rocks ; but " dip-slip-strike fault," or "strike-slip-dip fault" seems a cumbersome terminology for practical use.

The last two chapters in the book are devoted to structures in igneous rocks and petrofabric analysis and both give much useful information.

The illustrations throughout the book are numerous and well executed and it is particularly pleasant to have some photographs from localities in Victoria where interesting structures may be studied. It is to be hoped that this book will have the wide circulation it well deserves and its moderate price should help to secure this.

G. L. E.

GEOLOGY OF THE IRON-ORE FIELD OF SOUTH CUMBERLAND AND FURNESS. By K. C. DUNHAM and W. C. C. ROSE. *Wartime Pamphlet* No. 16. Geological Survey. pp. 26. 1941. Price 1*s.* 3*d.*

In view of the present great demand for low-phosphorus haematite ores it was very fortunate that H.M. Geological Survey undertook in 1937–8 an investigation of the future resources of the South Cumberland and Furness field, which is said to have produced to date something of the order of eighty million tons of high-grade ore. Unfortunately, however, the results of the work do not seem to offer much prospect of further large-scale developments. In particular, the geological structure is not favourable for the occurrence of large ore-bodies under the Duddon estuary, south and east of Hodbarrow, as has often been suggested. This area probably consists mainly of the basement beds of the Carboniferous, which are not favourable to ore-formation, or possibly of pre-Carboniferous rocks.

A point of much interest is that all ore-bodies die out downwards at a depth of 600 feet or a little more and are clearly related to the pre-New Red Sandstone surface. No evidence at all was found favouring a deep-seated origin by ascending solutions. The iron was clearly derived from above.

The Carboniferous succession in this region is now found to range from C_1 to D_3, and of the local subdivisions the Martin Limestone (C_1–C_2) and the Red Hill Oolite, C_2, are the chief ore-bearing members.

On the Cumberland side of the Duddon, the lowest beds of the New Red, which include brockrams and magnesian limestones, are lumped together as the Kirksanton Beds, and a boring at Barrow showed a maximum of 2,080 feet of St. Bees Sandstone. Walney Island is underlain by gypsiferous marls with thick beds of salt belonging to the Keuper, separated from the mainland by a continuation of the South Cumberland boundary fault, which farther north must have a throw of at least 1,800 feet. The Report contains many details of great interest which cannot be enumerated here.

R. H. R.

GEOLOGICAL MAGAZINE

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Hecla Hoek Rocks of New Friesland (Spitsbergen)

By W. L. S. FLEMING and J. M. EDMONDS

INTRODUCTION

NEW Friesland comprises the north-east part of the main island of Spitsbergen and forms a peninsula over 55 miles long from north to south, with a maximum width of 25 miles. It is bounded on the west by Wijde Bay and on the east by Hinlopen Strait and Lomme Bay, while to the south of it are the Stubendorff Mountains and the Veteran and Chydenius Ranges of Central Spitsbergen.

The interior of the Peninsula, rising to a maximum height of 3,350 feet above sea level, is hidden by a continuous covering of ice. The highest areas of ice form a number of broad, gently arched domes up to 7 or 8 miles in diameter, and these are separated from one another by wide shallow sags, some of which extend right across the ice-sheet leading back from the heads of peripheral valley glaciers. This indicates that the valleys in which glaciers flow are continued beneath the ice cap itself. The relief from the summit of the domes to the bottom of the sags is of the order of only 200 feet. Thus, whilst the surface of the ice sheet reflects the character of the sub-glacial topography, it does so only to a limited extent, and the term *Highland Ice*, as defined by Tyrrell,[1] is an appropriate designation.

Since the domes rise to approximately accordant levels it may be assumed that the sub-glacial terrain of the central part of New Friesland is an extension of the surface of a youthfully dissected peneplain, bevelling the structure of the rocks, which is exposed at several places along the fringes of the Highland Ice. This peneplain is believed to have been formed in late Cretaceous times and to have been raised to its present elevation along north-south Tertiary faults which define the limits of the peninsula.

Near the margin of the ice sheet there are several high semiindependent ice-domes, of which the Valhal Dome is the most prominent. This is separated from the main ice sheet on its western side by the north to south ice-filled depression at the head of Duner Glacier. The eastern side of the Dome is peculiar in as much as this is the only place where the ice spills into the sea. Elsewhere the highland ice has receded from the coastal areas and glacial outflow takes place by way of valley glaciers, which descend steeply in valleys cut into the peneplain.

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[1] Tyrrell, G. W., The Glaciers of Spitsbergen. *Trans. Geol. Soc. Glasgow*; xvii, 1922, 1–49.

Extensive areas of rock are exposed in these coastal areas, and being reasonably accessible from the shore, they have been studied by the geologists of those scientific expeditions which have visited this part of Spitsbergen. Thus, C. W. Blomstrand and A. E. Nordenskiöld visited it as members of two Swedish Expeditions in 1861, Gerard de Geer during the course of the Swedish-Russian Arc of Meridian Expedition of 1898–1902, and A. Hoel and O. Holtedahl with Norwegian Expeditions from 1909 to 1912. In more recent years N. E. Odell was in the southern and south-eastern parts of the region with the Oxford Expeditions of 1921 and 1923, and O. Kulling, in the summer of 1931, visited exposures on the east and north coasts of New Friesland, during the course of the Swedish-Norwegian Expedition under H. W. Ahlmann's leadership.

Kulling has introduced the results of his own investigations in North-East Land by a clear summary, both of the work of those geologists who have previously visited the area, and also of the conclusions reached by those who have studied neighbouring regions, where similar rocks occur. It is thus necessary here to recapitulate only such features of this previous work as relate to the particular problems with which this paper is concerned, and to refer the reader for fuller details to Kulling's paper[1] and the references which he cites.

The rocks on the eastern and western sides of New Friesland were found to be markedly different from one another, particularly as regards the grade of their metamorphism. On the west are highly crystalline rocks, principally granitic gneisses and mica-schists (frequently garnetiferous), both of which are invaded by granitic dykes and veins. On the east is a varied series of folded and faulted sediments in a much lower grade of metamorphism and lacking penetration by granitic magmas. These latter sediments, known as the Hecla Hoek Formation, consist principally of unfossiliferous crystalline limestones, dolomites, quartzites, and slates. The boundary between these two differing suites of rocks runs southwards from Treurenberg Bay (also known as Sorg Fjord). There are two main problems in the way of obtaining an adequate picture of the geology of these rocks.

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[1] Kulling, O., The "Hecla Hoek Formation" round Hinlopenstredet. *Geografiska Annaler*, 1934, xvi, 161–254.

(1) In the first place there is the question of the relationship between the two suites. This had presented difficulties because the boundary between them had nowhere been seen, being concealed under ice or superficial deposits. Blomstrand could find nothing to suggest a sharp boundary, and he regarded the entire rock formations of New Friesland as an originally connected series, of which the crystalline rocks in the west are the oldest. Nathorst considered members of the highly crystalline rocks in the west to be the metamorphic equivalents of the Hecla Hoek rocks in the east. Odell, from observations in the vicinity of the Lomme Bay Glacier, farther to the south, subscribed to a similar interpretation. Hoel and Holtedahl also supported Nathorst's view and maintained that the granites in the west of Spitsbergen are younger than the Hecla Hoek rocks, being intruded partly before and partly a little later than the intensive folding of the Hecla Hoek rocks. De Geer, on the other hand, believed the crystalline rocks to be Archaean, and thought that they were brought up against the younger Hecla Hoek formation by a north-south fault running parallel to the fold axes of the Caledonian Mountain System. A. E. Nordenskiöld also believed the gneisses to be quite separate from and older than the Hecla Hoek rocks.

Kulling did not have the opportunity to visit the western part of New Friesland, but, in summarizing Blomstrand's work, he emphasizes a point which later geologists seem to have overlooked. In the Verlegen Hook range, which forms the northwestern promontory of New Friesland, Blomstrand found that granitic gneisses form the real core of this high standing peninsula. To the west, as well as to the east, the granitic gneisses give place to veined gneisses and these, in turn, to a series of mica-schists and quartzite-schists. In other words there is a progressive decrease in grade of metamorphism westwards as well as eastwards from the granitic gneiss zone. Furthermore, into the series of less highly metamorphic rocks granite dykes are intruded accordant with the direction of strike. From this it follows that the metamorphism which produced the granite-gneisses and mica-schists must be younger than the folded series of rocks which here outcrop to the west as well as to the east of them, and that the intrusion as well as the metamorphism must have occurred at the time of that folding.

All this former geological work had necessarily been restricted to exposures easily accessible from the sea. In 1933 New Friesland was visited by the writers, who contrived to cross the ice cap from north to south and work along any outcrops which might be free from ice along the immediate boundaries of the highland ice, particularly those on the eastern side, some of which, it was hoped, might include the critical boundary zone between the rocks of east and west New Friesland.

(2) The second problem upon which it was hoped that we might be able to contribute information was on the structure and succession of the less highly metamorphosed rocks. The localities examined by us are complementary to Kulling's work. He studied certain exposures not far to the east of those which we examined. Unfortunately, the results of his work were not available to us at the time of our expedition, but in most instances it has been possible to correlate the formations which we studied with the succession that he established.

Kulling's Classification of the Hecla Hoek Rocks.

On the basis of investigations in the neighbourhood of Murchison Bay, on the west coast of North-East Land, Kulling established a complete succession embracing the whole of the series of sediments included in the name "Hecla Hoek". These sediments overlie the fine-grained porphyries, porphyry-agglomerates, and tuffs which occur in the Cape Hansteen Peninsula of North-East Land, and which are grouped collectively as the Cape Hansteen Formation.

The classification is as follows :—

The Cape Sparre Formation.—800–850 m. in thickness.

Consists of an upper and lower series, each successively built up with shales at the base followed by quartzose and slaty sandstones and then by dark coloured dolomitic rocks.

Fossils were found in a black-grey dolomitic mudstone forming the uppermost beds at Cape Sparre. The fossils consist of inarticulate brachiopods, mainly of the *Lingulella* and *Obolus* types. Trail marks of various types were seen on bedding planes.

The Sveanor Formation.—150 m. in thickness.

Consists of tillites with associated sandstones and varved marls. These tillites, regarded by Kulling as marine, are typically green-grey, grey, or red-brown laminated shales together with sandstones. They contain numerous boulders, some of which are striated. The thickness of the formation is very variable in different localities.

The Murchison Bay Formation.—Approximately 3,000 m. in thickness.

This formation is subdivided as follows (the section disclosed on the north side of Murchison Bay being taken as typical) :—

The Ryssö Series. 850 m.–1,070 m.

Typical "Ryssö-dolomites" rich in oolite and stromatolite dominate the middle and lower part of the series. It also includes dark-grey dolomites, dark dolomitic limestones, and a fair amount of slates and limestones. Layers of chert concretions, intraformational chert-conglomerates, and edgewise conglomerates are also present.

The Hunnberg Series. 500 m.

Grey-black and grey limestone and dolomitic limestone. In the middle of the series there are lighter coloured limestones with subordinate red-brown limestone and brown shale. Horizons of chert-concretions, chert-conglomerates, and phosphorite-concretions also occur.

The Sälodd Series. 260 m.

Greenish-grey dolomitic siltstones, and shaly dolomite in North-East Land ; and dense impure quartzite with some dolomitic shales on the west side of Hinlopen Strait.

The Raudstup Series. 300 m.

Reddish-brown and greenish-grey slates or shales, sometimes rather calcareous and often beautifully laminated.

The Norvik Series. 350 m.

Green-grey to grey sandstones and slaty sandstones are predominant. Grey, green-grey, grey-black, and red-brown shales occur, also white quartzose sandstones. Muddy and calcareous sandstones occur subordinately.

The Flora Series. 630 m.

White, pink, and green-grey quartzose sandstones.

The Cape Hansteen Formation.

This is of unknown, but very considerable thickness. Grey-green to green porphyry is the most important member of the formation, but there are also red and grey porphyry, quartz-phyllites, agglomerate, and conglomerate.

The total thickness of sedimentary strata above the Cape Hansteen Formation in Kulling's type area is, in round figures, 4,000 metres.

Kulling also visited areas on the main island of Spitsbergen on the west side of Hinlopen Strait, and was able to correlate the succession at Faxevika on the west side of Lomme Bay with that of his type area in North-East Land by the identification of all the units of the Murchison Bay Formation. In the Hecla Hoek region (Heclahoekfjellet), east of Treurenberg Bay, correlation was found to offer greater difficulties, but Kulling believes that here too the rocks belong to the Murchison Bay Formation, although they are slightly more metamorphosed. He attributes certain discordant features in the rock succession in this area to rather intense tectonic disturbances, some of the rock series having perhaps been thinned out or even eliminated by the folding movements.[1]

Field Observations.

The new areas which we studied in 1933 included—

(*a*) The Syd Range on the east side of the Duner Glacier and thence eastwards to " Gorge Valley ".

(*b*) The Rosen Mountains on the west side of the Duner Glacier.

(*c*) Outcrops farther south on the east fringe of the Highland Ice at the head of Gullfaxe Glacier.

(*d*) A few outcrops on the west side of the Highland Ice at the head of an unnamed valley glacier flowing west to Wijde Bay.

Some observations were also made in the Lomme Bay Glacier previously visited by the Cambridge Expedition of 1932,[2] and by N. E. Odell in 1923.

(*a*) THE SYD RANGE AND THENCE EAST AND NORTH-EAST OF THE DUNER GLACIER AS FAR AS GORGE VALLEY

The clearest succession obtained was that of rocks making up the Syd Range (the east wall of the Duner Glacier) and thence eastwards as far as an unnamed valley which we called " Gorge Valley ". The succession was obscured in several places by a covering of snow and ice, but it is believed that a fairly complete sequence was observed.

The Syd Range forms a scarp face more or less along the strike of the strata. It rises to its highest point at 1,650 feet above sea level at about the middle of its length, and from this point falls gradually in altitude southwards to disappear under the ice-cap.

The strike of the beds varies from N.N.W.–S.S.E. in the south to N.–S. at the northern end of the range. The angle of dip varies from vertical to 40° to the east.

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[1] *Op. cit.*, p. 218.

[2] Fairbairn, P. E., The Petrology of the Hecla Hoek Formation in Central Spitsbergen. *Geol. Mag.*, lxx, 1933, 437–454.

The succession exposed in the cliff face is as follows :—

D. Thin series of quartzites and shales.
C. Regularly bedded, massive white, pink, and green quartzites.
B. Contorted, grey sandstones with thinly-bedded, black, laminated shales.
A. Pink and light-grey quartzites.

Series A.—Pink and light grey quartzites, certain beds of which have ripple-marked surfaces, are interbedded with very thin shale bands and shale lenticles, which in places have a phyllitic character. The series has a vertical dip and is jointed vertically almost at right angles to the bedding planes. The jointing gives a columnar structure to the rock, so that it stands in imposing pillars and crags of great height. The observed thickness exceeds 300 feet.

Series B.—Contorted grey sandstones with thin-bedded and laminated black shales reach a total thickness of 300 feet. The shale bands, which are rarely more than 3 inches in thickness, are cross-cleaved and the whole series, except for the more massive interbedded quartzites, shows minor folding and contortion. The general dip is about 40° to the east at the summit of the section, but it gradually steepens in the lower part of the exposure. The series is developed both at the south end of the scarp and also at the extreme north end. The strike swings from N.W.–S.E. at the south end to due north to south at the north end.

Series C.—Even-bedded white, pink, and green quartzites reaching a thickness of 120 feet are overlain by some 200 feet of pink quartzites, which have their greatest development farther north, where they make up most of Syd Mountain. The distinctive coloration of the quartzites is mainly due to the presence of mica developed by the metamorphism. The strata conform in strike to the adjacent series, and a measured dip was 70° to the east.

Series D.—There is a thin development of more shaly material with some dark sandstones exposed at the top of the scarp and dipping eastwards, so that the greater part is hidden beneath snow and ice cover on the east side of the summit. The shales are dark grey and laminated, with a marked cross-cleavage.

We shall endeavour to interpret the above succession in the light of Kulling's classification. The distinctive rocks are the massive brightly coloured quartzites of Series A and C, which may at once be identified with the Flora Series at the base of the Murchison Bay Formation. There is indeed a large discrepancy in thickness when they are compared with the North-East Land development, but they correspond more closely with the measurements made in other parts of the mainland at Faxevika in the Lomme Bay area (Kulling, *op. cit.*, p. 207), and in east central Spitsbergen by Odell,[1] and the section measured by K. S. Sandford on Low Island.[2]

The Syd quartzites contain shale lenticles and thin bands, some of which have a phyllitic character. In this they differ from the Flora Quartzites of the type area, but again resemble the Faxevika occurrence, where also the series is isoclinally folded and repeated in conjunction with higher members of the Murchison Bay Formation.

Series B and D, with their greater proportion of shaly and phyllitic material within dark sandstones and thin-bedded quartzites, may be compared with the Norvik Series, as described by Kulling from Faxevika.

Owing to the absence of a clear section *across the strike* in the Syd district, we cannot say from field evidence what the exact relationship between the various series is, but from our recognition of the characteristic Flora Series alongside the more argillaceous beds of Norvik type, we conclude that these two series are here repeated by isoclinal folding. Further, owing to the nature of the exposures, our measurements must be regarded as a minimum estimate of the thickness of the strata, for the variation in dip suggests an attenuation or pinching-out of parts of the series, while in the case of Series A it is likely that part is hidden beneath the Duner Glacier. Along with the folding there has been metamorphism sufficient to produce moderate changes in the rocks.

The area to the east and north-east of the Syd Range was visited and examined by descent from the Valhal Névé Dome which lies to the south. In succession from west to east there are the following topographic units :—

1. The Syd Range.

2. A glacier, which we called the Syd Glacier, flowing northwards to join the Duner Glacier. This glacier was crossed at a southerly point.

3. A ridge of Red Quartzites which includes Points 585 and

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[1] Odell, N. E. The Geology of the Eastern Parts of Central Spitsbergen. *Quart. Journ. Geol. Soc.*, lxxxiii, 1927, 147–162.

[2] Sandford, K. S. The Geology of North-East Land. *Quart. Journ. Geol. Soc.*, lxxxii, 1926, 615–665.

640 of De Geer's map. This ridge is broad in the north, but divides into two branches at its south end, the branches being separated by a snow-filled hollow some 500 yards broad. The eastern branch forms the west walls of " Gorge Valley ".

4. " Gorge Valley " contains a short glacier which terminates towards the north in an end moraine. To the north of the moraine is flat ground, composed of a limestone series to be described, and cut by a narrow gorge excavated by waters issuing from the glacier. The gorge is directed north-north-west towards the north-east flank of the Duner Glacier. Gorge Glacier itself does not join the Duner Glacier.

5. Farther east there is a series of ridges running parallel to the strike of the rocks. The first one joins the east wall of Gorge Valley. Succeeding higher ones were not visited, but from a distance the nearer ridges appeared to be formed of light-coloured quartzites.

The ridge which lies to the east of the Syd Glacier consists of quartzites, predominantly red, but with members which are green and white in colour. They are of characteristic " Flora " type and show that there is a repetition of that series over a considerable horizontal distance.

Continuing eastwards the quartzites give way to laminated slates and dark quartzites of " Norvik " type forming the west side of Gorge Valley at its southern end, associated to the east with well-banded yellow siltstones and mudstones.

The succession across the north end of Gorge Valley (in the neighbourhood of the Gorge) is given below from west to east, that is in order of superposition.

East.		Laminated slates, weathering yellow-green.	Sveanor Formation.
		Green and purple cleaved slates.	
		Purple cleaved slates with granitic pebbles and boulders included.	
	20 feet.	Light calcareous conglomerate and lime-cemented oolite.	
	350 feet.	Pale grey and white banded limestone.	
	100 feet.	Grey massive limestone with calcite veining.	
	120 feet +.	Yellow-green banded siltstones, flaggy, and well cleaved.	
	500 feet.	White massive limestone and dolomite with cherty limestones.	
	120 feet.	Dark grey limestone with calcite veining.	
	200 feet.	Light grey massive limestone with banded grey limestone.	
	220 feet.	Black shaly limestone with calcite veining.	
	60 feet.	Grey limestone with calcite veining.	
	250 feet.	Black shaly limestone and dark grey limestone.	
	450 feet.	Grey limestones and dolomites.	
West.	300 feet +.	Dark shales.	

All the rocks strike north-north-west to south-south-east and dip vertically, or with high angles to the east.

The limestone series comprises a diverse and interesting group of sediments. Besides the more normal limestones, dolomites, and crystalline marbles, which reach a great thickness, there are cherty limestones, calcareous sandstones, and limestone breccias, in which angular fragments of porcellanous limestone are cemented in a dark matrix of coarsely crystalline calcite.

In the uppermost beds, immediately underlying the Purple Slates, there is a light-coloured coarse sandstone with calcareous cement. In the microscope slice it is seen to consist principally of quartz and felspar in rounded grains set in a calcareous matrix. The quartz grains show strain shadows, and the felspar, which is subordinate in amount, is principally oligoclase, with some microcline also present. In addition there is a little detrital tourmaline and rutile. The calcite occurs as small grains or well-formed rhombohedra in the matrix, but occasionally also as rounded grains, similar in size to the quartz. The larger individual grains generally lack definite outlines. Instead, they are penetrated irregularly by calcite, while in other instances the quartz grains have a secondary development of crystalline quartz at their borders forming elongate crystals.

Other coarse calcareous grits in the same group of sediments contain individual quartz grains up to three-sixteenths of an inch in diameter. Each grain is formed of a number of small interlocking crystals, as though derived from a compact quartzite rather than from a loose sandstone. These quartz grains are surrounded by a film of finely crystalline calcite grading into more coarsely crystalline limestone cement. Small calcite spheres which are also present show the pronounced concentric structure of oolites.

The calcareous and dolomitic rocks of Gorge Valley reach a thickness of approximately 2,400 feet. They are presumed to include the Ryssö and Hunnberg Series as defined by Kulling, but do not reach the thickness, totalling some 4,000 feet, which he gives for the development in North-East Land. Kulling's classification was not available to us when the examination was made, and under the circumstances no good would be served by suggesting from our record a boundary between the two series in the Gorge Valley area. With regard to the discrepancy in the recorded total thickness of the two series, the alternatives appear to be either that the Upper Murchison Bay Formation in our area does not reach the same thickness as that of the type area, or that in Gorge Valley the upper part of the Ryssö

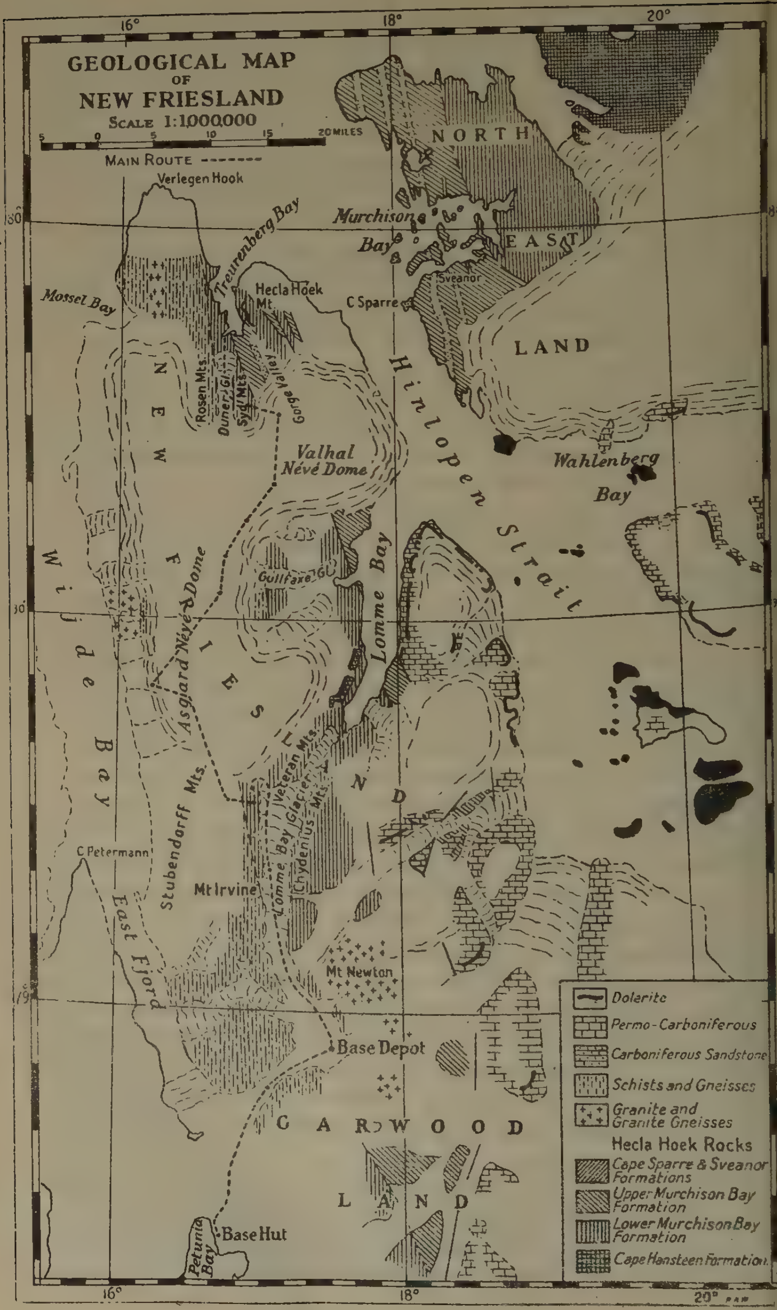
Series is missing. There is no satisfactory estimate of the thickness of the two series in any other locality on the mainland of Spitsbergen, and it is not certain that the full development on the west side of Hinlopen Strait is comparable to that on the east.

On the other hand Kulling, in making his correlation (*op. cit.*, p. 229, and our Table I, p. 419) with the succession given by Odell for East Central Spitsbergen, regards the upper part of the Ryssö Series as being absent there. Owing partly to our failure to find certain typical Ryssö dolomites in the Gorge Valley rocks we have preferred to regard the Series, as developed in this locality, to be incomplete and the upper part to be missing.

We are left with the weakest link in our correlation of the rocks in this area with the standard classification which we have accepted. The difficulty comes in the precise identification of the members lying between the Hunnberg and the Norvik Series—that is, the Sälodd and Raudstup Series. The difficulty may be due in part to our own incomplete field examination, for although we noted some 300 feet of dark shales below the limestone series we were unable to link up the succession with the Norvik rocks farther west. At the same time we are bound to note that Kulling fails to establish on the mainland of Spitsbergen, either at Faxevika (*op. cit.*, p. 207) or at Heclahoekfjellet (p. 216), rocks which are readily identified with the Sälodd and Raudstup Series of North-East Land.

The fine-grained slates, forming the east side of Gorge Valley and lying above the limestones, undoubtedly belong to the formation which Kulling refers to as the Sveanor Formation. The slates are of two colours, a purple group overlain by a green group, the upper one, however, containing segregations of purple coloured material. Otherwise they resemble one another in being fine-grained fissile slates. The purple group was found to contain pebbles and boulders of a pink granite up to 1 and 2 feet in diameter, and these boulders are all well-rounded and much weathered. Their distribution is very irregular and they appear to have sunk into the fine material of which the slates are composed as it was being deposited. It is important to note that these rocks conform in strike and dip to the limestone series.

Under the microscope the slates show rounded and subangular fragments of quartz, generally showing strain-shadows, set in a finer matrix of angular quartz and sericite aggregates with iron ores. Calcite is present in the matrix and also appears


GEOLOGICAL MAP OF NEW FRIESLAND
SCALE 1:1,000,000
5 0 5 10 15 20 MILES
MAIN ROUTE
16°
18°
20°
80
79
Verlegen Hook
Treurenberg Bay
Mossel Bay
Hecla Hoek Mt.
Rosen Mts.
Duner Gl.
Syd Mts.
Gorge Valley
Murchison Bay
C Sparre
Sveanor
NORTH EAST LAND
Hinlopen Strait
Wahlenberg Bay
Valhal Névé Dome
Gullfaxe
Lomme Bay
NEW FRIESLAND
Wijde Bay
Asgiard Névé Dome
Stubendorff Mts.
Veteran Mts.
Lomme Bay Glacier
Chydenius Mts.
C Petermann
East Fjord
Mt Irvine
Mt Newton
Base Depot
GARWOOD LAND
Base Hut
Petunia Bay
Dolerite
Permo-Carboniferous
Carboniferous Sandstone
Schists and Gneisses
Granite and Granite Gneisses
Hecla Hoek Rocks
Cape Sparre & Sveanor Formations
Upper Murchison Bay Formation
Lower Murchison Bay Formation
Cape Hansteen Formation

to form pseudomorphs after some decomposed grains possibly of an original felspar. In one instance it also occurs in well-rounded grains with iron-stained rim. There is a little plagioclase felspar present, also a little biotite and a few fragments of tourmaline.

The granite boulders are extremely weathered. Quartz only remains fresh ; the ferro-magnesians have gone to chlorite and the felspars are highly sericitized. The felspars, where distinguishable, are shown to be of large size and in a few there are traces of lamellar twinning. Some apatite and euhedral magnetite are present. Cracks in certain crystals have been filled by a new development of quartz and sometimes felspar.

The type locality of the Sveanor Formation is at Sveanor on the shore south of Murchison Bay, North-East Land. It has there a maximum thickness of 150 metres and consists of tillites, which take the form of laminated shales and sandstones containing numerous boulders, many of which are striated. Kulling has discussed the composition of this deposit in relation to its mode of origin (*op. cit.*, p. 224). At Sveanor the boulder and pebble material was chiefly derived from the upper part of the Murchison Bay Formation and consisted principally of dolomite of Ryssö type. No examples of the three lowest series of the Murchison Bay Formation or of the Cape Hansteen Formation were found among the boulders. The boulder material, other than dolomite, was igneous with some slates. Most of the igneous rocks were surface volcanics of trachyte, spilite, amygdaloidal basalt, and basic tuffs. There were also hypabyssal rocks consisting of granite-porphyry, granophyre, and granite-aplite, and finally a small content of grey medium-grained granite, but a complete absence of gneiss and coarse-grained granite.

Kulling suggests that the volcanic rocks have come from within the Ryssö Series sedimentary area, and that the volcanic activity took place in the time interval between the Ryssö Series and the Sveanor Formation. The volcanic area is still unknown and the absence of orogenic effects in the areas examined is explained by assuming that these effects were confined to the sediment-producing areas and that traces of the activity in the surrounding deposition areas were solely in the form of changed sedimentation.

The Sveanor tillite is to be regarded then as a marine tillite, containing no arkose-like marine beds, but formed probably by englacial material deposited slowly at the bottom of the sea. The finer material has undergone extensive sorting by currents and waves during transportation, and it appears in the deposit as a uniform matrix, into which the boulders have dropped directly from melting icebergs, so that they occur sometimes infrequently and at other times in profusion.

In the Gorge Valley occurrence the boulder material of these beds is in contrast to that of the type locality, in as far as it consists exclusively of a fine-grained granite, with dolomitic and volcanic boulders entirely absent. At first sight this might seem to invalidate the arguments of Kulling on the origin of the formation set out above. Field examination, however, led us to the conclusion that the boulders had been deposited into the finer matrix penecontemporaneously. If we accept the deposit as being a marine tillite, it is reasonable to expect that the character of the boulder material will vary widely in different districts and that the deposit will rest on various horizons of the Ryssö Series in different localities. We believe that the upper part of the Ryssö Series is missing at Gorge Valley and its erosion in this area may have provided material for the deposit at Sveanor to the east. Thus, within certain narrow limits, the Sveanor Formation may be regarded as varying in age in the separate localities in which it occurs and this is quite in accordance with its glacial character.

During our subsequent field work we failed to locate the granite, which had provided the boulder material, in situ, and we are unable to suggest even the direction from which it is likely to have come.

Glacial boulder beds of Hecla Hoek age have been described by Garwood and Gregory [1] at Fox Point in Bell Sound and by Holtedahl [2] at St. John's Bay, south of King's Bay. For a comprehensive discussion on the relation of the Spitsbergen tillites to those of similar character in East Greenland and Scandinavia reference should be made to Kulling's paper (p. 233 *et seq.*).

(*b*) THE ROSEN MOUNTAINS

On the west side of Treurenberg Bay (Sorgfjorden) and the Duner Glacier there is a broken plateau about 1,750 feet high, extending westwards towards Wijde Bay. The northern part across from Treurenberg Bay to Mossel Bay was examined by Blomstrand in 1861 and the reassessment of his results by Kulling has already been referred to on page 407 of this paper.

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[1] Garwood, E. J., and Gregory, J. W., Contributions to the Glacial Geology of Spitsbergen. *Q.J.G.S.*, 1898, liv, 197–227.

[2] Holtedahl, O., Zur Kenntnis der Karbonablagerungen des westlichen Spitsbergens. II Allgemeine stratigraphische und tectonische Beobachtungen. *Vid-Selsk. Skr. I M-N Kl.*, 1912, No. 23, 57.

Succession in North New Friesland	Our Suggested Correlation	O. Kulling's Classification in North-East Land	Kulling's Suggested Correlation, p. 229	N. E. Odell's Classification in East Central Spitsbergen
— Cleaved silty slates } Gorge Slate and boulder bed } Valley	Missing ←	*CAPE SPARRE FORMATION* *SVEANOR FORMATION*	Missing Missing	— —
	? Upper part missing	*UPPER MURCHISON BAY FORMATION*		*Upper Series*
Limestones, dolomites, dolomitic conglomerate, oolites, and cherts with some shales, to thickness of 2,400 feet	←	Ryssö Series, 850–1,070 m.	Upper part missing → centre part → lower part →	(7) Cherty conglomerate. (6) Black and white chert-horizon. (5) Pale and dark dolomites and limestones of great thickness, often veined with calcite and dolomite, including an " intra-dolomite conglomerate " present in Bear Island, and a (?) fossil horizon of oolite and " oolitoid " rock or " Ryssö-dolomite ".
	↖	Hunnberg Series, 500 m.	part → ? part	(4) Red shales, with thin quartzites and quartzose slates.
		LOWER MURCHISON BAY FORMATION		*Lower Series*
300 feet +. Dark shales Gap in record	←	Sälodd Series, 260 m. Raudstup Series, 300 m.	?	(3) Dark dolomitic limestones and pink and grey streaked marbles.
Laminated black shales and dark quartzites Series B and D, etc.	←	Norvik Series, 350 m.	→	(2) Dark laminated shales or siltstones, hard buff-coloured and blue slates weathering green, often spotted and interbedded with pink quartzite.
Syd Quartzites Series A and C, etc.	←	Flora Series, 630 m.	→	(1) Purple massive quartzite Pink massive quartzite Yellow massive quartzite } About 1000 feet exposed.

Our own examination of this succession was made farther south and began with the west wall of the Duner Glacier—the Rosen Mountains of De Geer's map—and the plateau above it. A great part of the area was snow-covered and contacts were generally obscured, nevertheless the general sequence is clear and is given below, together with Kulling's observations (*op. cit.*, p. 219).

	West Side, Duner Glacier.	*West Side, Treurenberg Bay* (*Kulling*).
East.	Light coloured quartzites.	White to pink quartzite (Flora Series).
	Green schists or phyllites.	Grey phyllitic mica-schist and mica-quartz phyllite (Norvik Series).
	Dark coloured limestones.	Grey Marble (" Solitary Layer ").
	Green chloritic schists.	Grey phyllitic mica-schists.
	Light quartzites.	Light coloured mica-quartzites.
West.	Garnetiferous mica-schists.	

The succession is listed from east to west and is easily equated. The examination was not continued to the west, and we suggest that it could best be done late in the summer season when the snow cover has retreated from the plateau.

The light-coloured quartzites, principally pink, form the west boundary wall of the northern part of the Duner Glacier. They have a steep dip to the east and strike slightly west of north along the scarp. They resemble the Syd Quartzites and belong to the Flora Series. They are followed to the west by green quartz-mica-phyllites and schists. These rocks form the west wall of the glacier in its southern part and at " Ivory Mountain " the planes of schistosity are vertical and have their strike north to south. A set of joints from north-east to south-west dip steeply to the south-east. These schists are markedly quartzose in parts, with quartz lenses between the schist folia. Kulling suggests that similar rocks to the north are probably derived from the arenaceous slates and muddy sandstones of the Norvik Series.

Limestones follow the schists, and outcrops were examined on the north side of " Ivory Glacier "[1] and on the south side of the glacier next to the north, both localities being near the junctions of these subsidiary glaciers with the Duner Glacier.

The schists mentioned above give way to the limestones with the following stratification :—

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[1] This glacier is the most southerly tributary of the Duner Glacier on its west side and " Ivory Mountain " lies between the glaciers.

	Schist
6 feet.	Limestone
6 feet.	Schist
2 feet.	Limestone
2 feet.	Schist
	Limestone

The contact appears normal in every way and near the contact the limestone contains phyllitic partings and is fissile with a development of graphite. The limestones are generally dark in colour, but with some parts light and saccharoidal in character. There is much secondary calcite veining throughout the rock. The strike is slightly west of north in conformity with the adjacent schists, and the dip varies from 75° to west through vertical to 75° to east. The thickness is approximately 200 feet.

To the west of the limestones there are schists similar to those described above and they are followed by quartzites, light-coloured and massive, but showing marked contortion and having a development of muscovite throughout. Succeeding these is a wide area with garnetiferous mica-schists.

Looking upon the succession on both sides of the Duner Glacier as a connected whole, and bearing in mind the gaps in the sequence due to the presence of the glacier, the gradual increase in metamorphism westwards in the Lower Murchison Bay Formation may be observed while the various series may still be recognized far into the metamorphic zone by their general character and sequence.

We have already mentioned that in the Syd Range the shaly members and the partings between the quartzites have become phyllitic and that the quartzites themselves are partly altered with a development of muscovite on the surfaces. This alteration is progressively intensified on the west side of the Duner Glacier, where the same series of rocks are further metamorphosed. Blomstrand's view was that the whole succession westwards was a connected series with the most westerly crystalline rocks as the oldest, but it is now recognized that the lowest members of the Murchison Bay Series have been involved in intense folding and that they have been metamorphosed increasingly towards the west. It will later be shown that this is also the case in the Gullfaxe area to the south.

With regard to the western side of New Friesland we have some independent evidence to show that there is a decrease in metamorphism from the central crystalline zone in a westerly as well as in the easterly direction. A collection of rock specimens made by A. C. Geddes, one of the members of a party of our expedition which travelled the length of Wijde Bay, shows micaceous quartzites and slates and other more altered sedimentary material, and his notes refer to these rocks as occurring near the coast, while the hinterland to the east consisted of garnetiferous schists and gneisses.

(c) HEAD OF GULLFAXE GLACIER

The Faxe group of glaciers flow down from the east side of the New Friesland Ice-cap and terminate in the region of Mt. Faxe at the north end of Lomme Bay. The longest glacier of the group is Gullfaxe Glacier, and we examined the western end of this glacier from the point where the rock walls disappear under the ice-cap eastwards for a distance of 3 miles.

The first major glacier to join the Gullfaxe Glacier on the north side was, for convenience, named by us Carfaxe Glacier. It occupies a valley depression which runs northwards and appears to be connected with the head of the valley in which the Duner Glacier lies, for a sag in the ice-cap runs between the two glaciers, the sag separating the Valhal Dome from the main Asgard Dome. The east wall of this tributary glacier consists of brightly coloured quartzites resembling closely those of the Syd Range on the East of the Duner Glacier and, like them, the quartzites appear to belong to the Flora Series as originally defined. These characteristic beds afford a useful datum line for the interpretation of the rock succession in the Gullfaxe area. Along the Carfaxe Glacier the quartzites dip to the east at angles of between 45° and 70° and they are followed eastwards (down the Gullfaxe Glacier) by darker quartzites with phyllitic partings, quartzites with calcareous cement, mudstones, and phyllite and shale members. These rocks evidently belong to the Norvik Series, and it seems that the whole of the series examined belongs therefore to the Lower Murchison Bay Formation. The limestones of the upper part of this formation, if present, lie farther east between the area which we examined and the most western point reached by Kulling in the Mt. Faxe region.

It was to the west of the Carfaxe Glacier and on the south side of Gullfaxe Glacier that we were able to make our most detailed examination of the succession. Following on finely-cleaved black slates, which are probably altered rocks of the Norvik Series, forming the west side of Carfaxe Glacier, there is a repetition of Flora Quartzites, and these appear also on the south side of the main Gullfaxe Glacier where an important cliff section shows the full succession of rocks from Flora Quartzites at its east end to the point where the cliff is lost in the ice-cap to the west.

The succession of rock types is given below, being listed from west to east :—

?	J.	Gneiss with felspar porphyroblasts.
100 ft.	I.	Massive pink and white quartzites.
100 ft.	H.	Green schists, with some thin dark quartzites at the eastern end.
about 200 ft.	G.	Gneiss with pink felspar porphyroblasts resembling J.—concordant with foliation and bedding of series above and below.
about 100 ft.	F.	Banded green quartzose schists interbedded with thin dark-banded quartzites.
200 ft.	E.	Massive and fine banded red quartzites.
300 ft.	D.	Banded quartzites with green schists and banded quartz-schist.
50 ft.	C.	Compact quartz-mica-schist.
100 ft.	B.	Green schists and banded quartz-schist.
550 ft.	A.	Yellow, green, and red quartzites, rather thinly bedded.

An estimate was made of the thickness of each of the main groups, but they were not measured in detail. The whole of the strata have a vertical dip and strike due N. and S. at the foot of the cliff, but in the central part of the section (E to G) the dip at the top of the cliff is 75° to the west, although the bedding retains its verticality at the base.

There is *no discordance* apparent in the succession of strata given above, but it was noted that the rocks fall into three classes which are repeated. A, E, and I are light coloured, mainly pink and white quartzites. B, C, D, F, and H are green schists, phyllites, and quartz-schists, with subsidiary dark-coloured, thinly bedded quartzites. G and J are gneisses which are identical in character. Although no field evidence regarding order of superposition was noted and attempts at determining the exact relationship meet with difficulties, it is possible, by taking into consideration the succession as established in the north of New Friesland, to identify the rock types with some confidence and thereby to get some idea of the structure. The light-coloured quartzites are recognized as belonging to the Flora Series, resembling closely the types of the Syd Range and descriptions of these rocks in Kulling's paper. The quartzites are, in fact, the most distinctive series in the succession and form the most useful datum line throughout New Friesland and southwards to East Central Spitsbergen.

In the Gullfaxe succession the phyllites and quartz schists are believed to represent the Norvik Series, following the identification of similar rocks in the Rosen Mountains, west of the Duner Glacier. The phyllites vary from mere partings in the quartzite bands to beds of from 30 to 40 feet thick with subordinate quartzites. They are often permeated by small irregular veins of quartz and felspar. The rock succession, taken as a whole, leads one to suppose intimate folding with repetition of the members, and it is important therefore to note the occurrence of G and J, a rock type of gneissic character which is, however, closely associated with the sedimentary rocks of the Lower Murchison Bay Formation.

The gneiss is predominantly dark in colour and varies in texture from a schistose type to a more compact and homogeneous rock. In the former quartz and felspar alternate in bands, with fine dark phyllitic material, much of the felspar being in augen or knots. A thin section shows the rock to be much fractured. The chief constituents are quartz, orthoclase, and oligoclase felspar. The felspars in general are the larger crystals, the orthoclase particularly occurring in large irregular fragments, often fractured, with a fresh development of the same mineral in the cracks and often an infilling of quartz and sometimes of calcite. The orthoclase has a tendency to perthitic structure and, in certain places, crystals are partly cross-hatched after the microcline type of twinning. A certain amount of the potash felspar is microcline. The oligoclase felspars are not so abundant and in one instance show bending and fracturing of the twin lamellae. A little apatite is present and calcite fills some of the cracks. The phyllitic bands consist of quartz in small interlocking grains, bands of sericite and trains of chlorite and biotite, and they persist even when the quartz and felspar crystals show fracturing.

In the more compact type of gneiss the phyllitic partings are absent, but the finely banded structure is preserved. In the thin section the banding is seen to be marked by large flakes of biotite and also colourless mica, which wrap round the " augen " and are orientated in a common direction. Microcline does not appear, and the felspar augen are orthoclase with a tendency to perthitic intergrowth as in the other rock. There is also a smaller number of plagioclase (albite-oligoclase) augen. Apatite is also present and a large amount of rather granular sphene.

Rocks of the same gneissic and phyllitic types were found in the Lomme Bay Glacier in morainic material derived from the Veteran Mountains.

(*d*) Wijde Bay Coastal Area (West Side New Friesland Ice-cap)

We were able to make only a single visit to the west side of the New Friesland ice-cap, and on that occasion undertook a brief examination of the rocks at the head of an unnamed glacier in almost the same latitude as Gullfaxe Glacier (79° 30′ N. approximately). The rocks exposed in this area were pink granite-gneisses and foliated granite in the main, with sedimentary gneisses and schists at the eastern end. It is evident that the former represent igneous intrusions into the latter. The field relationship between the igneous rocks was not examined in detail, but they fall definitely into two types, one gneissic and the other more massive, with only slight foliation. This latter type contains dark-coloured xenoliths sometimes of large size, which appear to be incompletely digested fragments of country rock incorporated in the magma near the edge of the intrusion.

In addition to our own visit one of the parties of our expedition made a boat journey down the whole length of Wijde Bay, going ashore several times on the east coast. A. C. Geddes, a member of this party, has given us specimens which he collected at each landing place. Of necessity most of the specimens were from erratic boulders near the coast, but they were collected as being typical of the erratics which predominated, and as such they may be taken as representative of the rocks of the hinterland. In addition the specimens collected of rocks in situ allow us to obtain a general idea of the geology of this side of New Friesland.

In the Mossel Bay area in the north Geddes found fine-grained mica-schists in situ, this being in accordance with Blomstrand's observations which have already been noted as being of such significance in the most recent interpretation of the structure of this part of New Friesland. Some 5 miles south of Aldert Dirkes Bay were found slates and schists, some of which have been injected with vein-quartz and felspar. Still farther south Geddes made a landing in the neighbourhood of the granite-gneiss area, the eastern end of which we had also visited.

At another landing-place 20 miles south of here altered sedimentary rocks, including a coarsely crystalline limestone, were found. An island off the coast in this vicinity showed a varied group of altered sedimentaries of mica-schists and quartzites, with quartz veinlets throughout. The strike of the rocks was roughly N.N.E. to S.S.W. and the dip variable.

(*e*) LOMME BAY GLACIER

In this area our observations are subordinate to those of Odell and of P. E. Fairbairn. The object in this section is to attempt to link up their work with Kulling's classification by considering afresh the rock types they have described.

We entered the Lomme Bay Glacier about 10 miles north of Mt. Irvine and at this point finely laminated phyllitic slates and red, yellow, and white quartzites were found in situ, while the moraines of glaciers draining the west side of the glacier were composed largely of augen-gneiss of the type found at the head of Gullfaxe Glacier. It is evident that there is a transition zone here just to the west of the glacier and running parallel to it. Both east and west walls of the Lomme Bay Glacier in this part consist of red, yellow, green, and white quartzites of Flora type and quartzites with subsidiary shales and phyllites. The most striking feature in this district is the difference in dip on the two sides of the glacier—a dip of about 30° to the south-west on the west side of the glacier and of about 30° to the east on the east side. This central part of the Lomme Bay Glacier appears therefore to lie along the axis of an anticline in the Lower Murchison Bay Series, but the structure may not be simple.

In the region of Mt. Irvine, Odell (*op. cit.*, p. 155) found that " the lower Hecla Hoek quartzites and slates pass progressively with increasing metamorphism through phyllites into mica-schists ". Specimens of the " augen-schist " of Mt. Irvine correspond with our gneissic type from Gullfaxe Glacier, and Odell says that it is also found in Mt. Terrier to the south.

Farther south and west the Hecla Hoek rocks have been examined by Fairbairn. His description is mainly petrological and in his map he uses the terms " Western Schists and Gneisses " and " Eastern Slates and Quartzites ". This purely petrological classification is useful only in restricted localities and tends to make difficult the correlation of strata in other areas. From Fairbairn's description of the metamorphosed zone it is evident that the rocks to the east are exclusively altered sediments, whilst to the west altered igneous rocks are associated with the sediments. We assume that the eastern part of the metamorphic zone consists mainly of altered Lower Murchison Bay Series. A widespread series of amphibolites met by Fairbairn, and more recently by W. B. Harland in the Stubendorff Mountains is believed by both these observers to have originated as recurring flows of basalt interbedded with sediments. We did not meet this rock and do not feel competent to express an opinion on its origin, but if the above supposition is correct then rocks other than those which are present in the Hecla Hoek Formation of North-East Spitsbergen are involved in the Stubendorff metamorphic belt, and we must suppose that rocks of the Cape Hansteen Formation are here exposed.

Harland has given an excellent picture of the tectonics of the Stubendorff Mountains and the reader must be referred to his paper for full details. (Harland, W. B., Geological Notes on the Stubendorff Mountains, *Proc. Roy. Soc. Edinb.*, lxi, 1941, 119–129.) He emphasizes the disharmonic nature of the folding in which mica-schists function as incompetent beds and zones of thrusting, while the most competent appear to have been the marbles and foliated psammitic rocks. The whole appears to be the result of recumbent folding and thrusting with nappe structure in which overfolding to the west has taken place.

In the areas which we examined the sections were nowhere high enough to obtain any direct evidence on the nature of the folding. From the repetition of the strata in the Gullfaxe area, however, we came to the conclusion that overfolding and thrusting must have taken place. The discrepancy in thickness of our strata with that measured by Kulling in North-East Land has also led us to believe that either the Lower Murchison Bay Formation must be much attenuated on the mainland or, just possibly, that it is folded and repeated in North-East Land more than Kulling realized, and that his thicknesses are exaggerated.

SUMMARY AND CONCLUSIONS

(1) In each of the areas examined the transition zone between the Hecla Hoek rocks of Eastern New Friesland and the more highly metamorphosed belt has been observed and the evidence points to a gradual increase in metamorphism westwards with the same general series of rocks involved. The rocks have been isoclinally folded and repetition occurs more especially on the east flank of the intensely metamorphosed zone. Usually only the Lower Murchison Bay Formation appears in the more highly folded belt, but it may well be that in the Stubendorff Mountains other rocks are also included.

In the northern area, west of Treurenberg Bay, Blomstrand's recognition of a central core of granitic gneiss giving way on both sides to less highly metamorphosed types still stands as the most important contribution to the interpretation of the structure. Recent examination has revealed that the sequence of events has been a folding of the Lower Murchison Bay Formation followed shortly by igneous intrusion and metamorphism of the whole.

In the Gullfaxe area isoclinally folded rocks of the Lower Murchison Bay Formation are associated with a quartz-felspar-gneiss. We have not been able to decide what this rock was originally. It may be either a metamorphosed igneous rock or an altered arkose. It appears to be concordant with the adjacent altered sedimentaries, but may be igneous material in some way related to the large granitic intrusion which lies farther west in this latitude.

In the Lomme Bay area Odell observed the transition zone.

(2) In the less altered zone to the east of the Duner Glacier we have been able to recognize the members of the Murchison Bay Formation as defined by Kulling, and the correlation is set out in Table I. The least satisfactory identification is of the Sälodd and Raudstup Series. According to Kulling these Series have different characteristics in the Lomme Bay area from those which they show in North-East Land, and it may be that throughout New Friesland they attain neither the thickness nor the distinctive character which is theirs in the type area. The presence of the other members of the Murchison Bay Formation and of the remarkable Sveanor Formation is well established.

GEOLOGICAL MAP OF NEW FRIESLAND

The map has been compiled in order to bring the geological work of various workers into the classification proposed by Kulling. The information for North-East Land has been taken from the work of Kulling and Sandford ; that for New Friesland from Odell, Kulling, Fairbairn, Harland, and the present writers.

ACKNOWLEDGMENT

One of us (J. M. E.) wishes to record his special indebtedness to Professor J. A. Douglas, under whose guidance this work was begun.

The Hangnest Dolerite Sill, S.A.

By F. Walker and A. Poldervaart, Department of Mineralogy and Geology, University of Cape Town

(PLATE VIII)

ABSTRACT

A 500 ft. sill of dolerite from Hangnest in the Calvinia division of the Cape Province (South Africa) exemplifies very clearly two well-marked features of the thicker Karroo sills :—

(1) Very slight amount of crystallization-differentiation.

(2) Marked tendency to mobilize and react with the associated shales and siltstones.

A petrological and chemical study of this sill is given and the mechanism of the various processes discussed.

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INTRODUCTION

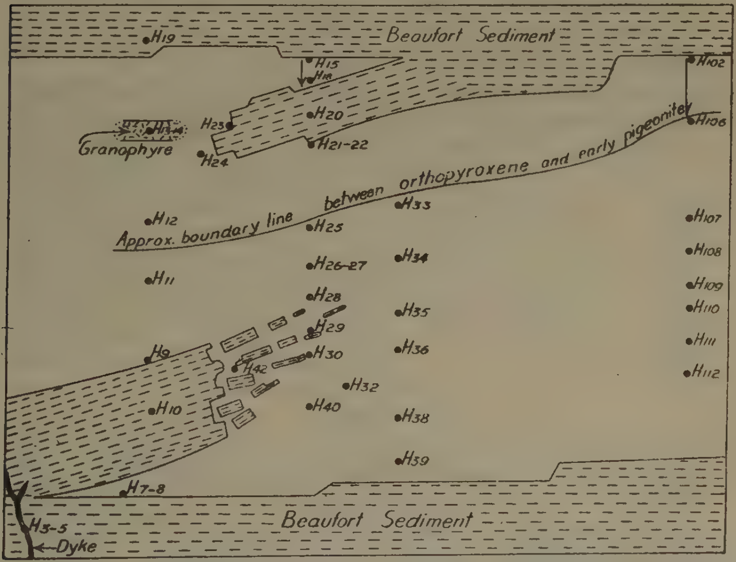
The following is the third of a series of publications on Karroo dolerites by the Geology Department of the University of Cape Town. A very brief description of the sill in question appeared in a previous paper on the dolerites of the Calvinia district (Walker and Poldervaart, 1941). The Hangnest sill affords interesting and typical examples of reaction between dolerite and Karroo sediment, and the dolerite itself is a widespread type in the Karroo suite, though this is not indicated by previous accounts.

The active behaviour of the Karroo dolerites towards the invaded sediment was pointed out by Mountain (1936) and again by the authors in a paper on the dolerite sill of Downes Mountain (1940). In neither of these papers was it found possible to define the nature of the reaction processes nor to distinguish between them. At Hangnest, however, three different types of reaction processes are clearly definable. In a paper entitled "The dolerites associated with the Karroo System, South Africa", Daly and Barth (1930) come to the conclusion that the Karroo dolerites are characterized by magnesian olivine and strongly zonal clinopyroxene. Examination of some 500 thin sections of Karroo dolerites collected over a large area has led the authors to believe that, although such types are certainly the most abundant, dolerites with different mineralogy are strongly represented in the Karroo suite. The Hangnest dolerite is an example of this, for here orthopyroxene occurs to the exclusion of olivine, and in addition three different clinopyroxenes are recognized.

FIELD RELATIONS

The farm Hangnest lies in a valley, 28 miles from Calvinia and on the road to Middelpost (31° 43′ S., 20° 2′ E.). The surrounding kopjes are all table mountains, rising roughly 700 feet above the general level of 3,500 feet. The strata overlying the sill form the steep cliffs of the mountains, whereas the dolerite is exposed on the gentler slopes below. The sediments are bluish to yellowish-grey ripple marked siltstones of Beaufort age, alternating with thin layers of shale. The normal dolerite is a rather coarse-grained rock which weathers in thick exfoliating slabs. The lower contact of the sill is exposed in a river running at the foot of the mountain in a N.–E. direction. Some distance further downstream two thin dikes are exposed; each ∓ 3 feet wide and 15 feet long. A strip of sediment 150 feet thick was stoped up by the magma in the manner indicated in Text-fig. 1. The end of this stoped block is irregular and smaller xenoliths are seen to have been broken off from it. The sediment is mainly argillaceous and altered by contact metamorphism to a fine-grained black hornfels. At the extreme end of this lower stoped block some of the hornfels xenoliths seem to have reacted with the magma, producing marginally a coarse-grained rock of lighter appearance than the normal dolerite.

Likewise a 50 ft. thick strip of sediment was stoped down from the upper contact. The sediment of this upper stoped block is identical with the normal Beaufort siltstone, though it becomes more argillaceous towards the base. Here, as in the lower stoped block, the contact with the dolerite is sharp and chilled except at the extreme end where it is irregular. A rheomorphic hornfels vein was found emerging from the base of the block and is intrusive into the basaltic dolerite. At the extreme end of the block a miniature breccia occurs, consisting of angular pieces of basaltic dolerite embedded in a matrix of mobilized sedimentary material. At the same level in the sill, and conforming with the strike line of the upper stoped block, an exposure of granophyre 20 feet thick was found. The exposure shows ill-defined division planes similar to the bedding and jointing planes of the upper stoped sediment. This granophyre will be called reaction-granophyre throughout this paper, as evidence from other Karroo sills (as yet unpublished) establishes its nature and origin beyond doubt. The rock is very distinctive in texture and colour, being unmistakable in the field. Hand specimens



TEXT-FIG. 1.—Diagrammatic section through the Hangnest sill showing localities of sliced specimens. Vertical arrows indicate series collected at short intervals.

show long, greenish-brown needles of ferromagnesians scattered with decussate arrangement through an abundant white quartzo-feldspathic base. Unfortunately at Hangnest exposures in between the reaction-granophyre and the upper stoped block are masked by boulders and rubble fallen down from the cliffs above. At approximately the centre of the sill a 4 in. vein of siltstone was encountered, running vertically and tapering downwards. This vein was followed over a distance of some 20 feet and was seen to send off stringers and veinlets into the surrounding dolerite. Presumably the vein originates from a hidden xenolith. At all levels in the lower parts of the sill irregular patches and schlieren of a coarse-grained dolerite-pegmatite were found. This shows as its most conspicuous macroscopic feature long blades of greenish or brownish-black pyroxene set in a white feldspathic base. In addition a thin felsic vein was found higher up in the sill, in which a few scattered flakes of brown biotite proved to be the only ferromagnesian mineral.

Several traverses were made along various gulleys running down the mountain sides and specimens collected at regular intervals as indicated in the sketch map.

CHILLED CONTACT BASALTS

The contact basalts show a few phenocrysts consisting of zonal plagioclase laths and untwinned, colourless prisms of magnesian orthopyroxene. Olivine is absent, though in one section a pseudomorph in bowlingite and magnetite was observed. The groundmass generally consists of plagioclase laths, elongated clinopyroxene and abundant minute magnetite granules, with or without large poikilitic plates of brown biotite. Occasionally the groundmass may be a devitrified, altered glass. The biotite is thought to have been produced by reaction of late, probably hydrothermal, solutions with iron ore. The same solutions seem to have enriched the extreme peripheries of orthopyroxene phenocrysts in $FeSiO_3$ and later converted them to a green, pleochroic amphibole.

TABLE I

Bronzite phenocrysts[1]	Av. γ: 1·687	Av. $2V\alpha$: 80°	Extreme values for $2V\alpha$: 88–79°	Av. Comp.: Of$_{17}$	Iron-rich Periphery $2V\alpha$: 60°	Av. diam: 0·5 mm. Max. diam: 1·9 mm.
Plagioclase phenocrysts	Av. β: 1·572	Av. Comp. An$_{72}$		Limits An$_{75}$–An$_{60}$		Av. size: 0·6 × 0·2 mm Max. size: 1·3 × 0·2 mm

The evidence from the basaltic contacts shows that the magma started to crystallize under intratelluric conditions with the simultaneous precipitation of a calcic plagioclase An$_{72}$ and a magnesian orthopyroxene Of$_{17}$. A chemical analysis of the upper contact was made (Table VI), but unfortunately the rock proved to be slightly altered, this being brought out by the $CaCO_3$ in the norm. It is nevertheless typical of the Karroo dolerite magma.

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[1] The authors follow the classification of the orthopyroxenes suggested by Hess and Phillips (1940). The compositions of bronzites are derived from their diagram.

TABLE II

PROPORTION OF PHENOCRYSTS BY WEIGHT

	H_3	H_7	H_8	H_{21}	Average
Plagioclase phenocrysts .	3·6	3·6	2·9	3·3	3·4
Bronzite phenocrysts .	1·6	·9	·8	·9	1·1
Total . . .	5·2	4·5	3·7	4·2	4·5

THE DOLERITE

Petrography

The normal dolerite consists of stout laths of plagioclase, sub-ophitic pyroxene, and interstitial micropegmatite ; while biotite, iron ore, and apatite form the accessory minerals. The texture approaches that of gabbroidal rocks.

Two series of specimens were collected at short intervals from the upper contact downwards. Both these series show the same characteristics, i.e. the disappearance of the phenocrysts and the rapid increase in grain size of the groundmass minerals, but the one series shows the development of an iron-rich interstitial mesostasis in place of micropegmatite in the other. The high elongation ratio of the plagioclase and pyroxene is typical of both series, the latter reaching values up to 30. A maximum of elongation appears to be reached 10–15 feet below the upper contact, after which the ratio decreases, though abnormal elongation still prevails. Examination of series of sections from the lower contact and junctions with the sedimentary stoped blocks shows that the same tendency for elongation exists there, though it is less pronounced.

Plagioclase

Plagioclase	Av. β 1·568	Av. Comp. An_{68}	Zoning An_{72}–An_{50}	Av. length 0·8 mm. Max. length 3·0 mm.	Av. elongation 3·4 Max. elongation 15

Zoning is usually progressive and continuous, though examples of oscillatory zoning and resorption and repair are occasionally encountered. The crystals are twinned on albite, Carlsbad, and pericline laws, Baveno twins being rare. On the whole the dolerite of Hangnest rather resembles that of Downes Mountain with the important exception that the plagioclase of the former has an average composition An_{68}, whereas the latter is of average composition An_{55} (F. Walker and A. Poldervaart, 1940).

Pyroxene

In the Hangnest sill four different pyroxenes are recognized. In our previous paper on the Calvinia dolerites (1941) these pyroxenes were discussed in some detail and a summary of their properties will thus suffice here.[1]

Additional Observations

(1) Many hypersthene crystals show a curious intergrowth, consisting of thin parallel sheets or small irregular patches of different double refraction. This intergrowth has been recorded by several petrologists from widely different areas, but no unanimity has as yet been reached as to its nature and origin. To illustrate this we may take the well-known example of the Palisade diabase sill, in which the intergrowth is shown very clearly. Lewis (1907) described the intergrowth as graphic and figured it as interpenetration twinning. In a later paper the senior author (1940) described the graphic intergrowth in the hypersthene of the Palisades and thought it to be produced by exsolution. Henry,[2] who examined the same sections, ascribed the phenomena to disorientation through strain. Finally Hess and Phillips (1940) suggest that the diopsidic lamellae in the orthopyroxene of the Palisades are produced by exsolution of diopsidic material on slow cooling. Therefore, in volcanic rocks no lamellae should be visible, in hypabyssal rocks the lamellae should be imperfectly developed and in plutonic rocks the lamellae should be well developed.

At Hangnest the intergrowth is mainly confined to the margins of crystals, though at higher levels in the sill it may occupy the entire surface of the bronzite (Of_{17}) individuals. The same tendency was found in the bronzites (Of_{17}) of the Downes Mountain dolerite (3). In the Palisade diabase, however, the intergrowth is mainly confined to the cores of hypersthene crystals, whereas the margins are always free from it (Walker, 1940). Here the orthopyroxene is of average composition Of_{35}. It appears, therefore, that the intergrowth manifests itself preferably in orthopyroxenes of compositions somewhere in between Of_{17} and Of_{35} and probably round about the compositions Of_{25}–Of_{30}. In this connection it is interesting to note that Hess and Phillips (4) record a possible discontinuity in the $MgSiO_3$–$FeSiO_3$ series at about the composition Of_{29}

---

[1] In this paper the following classification of the clinopyroxenes was adopted :—

hypersthene-augite 2V : 30°–50°
pigeonite 2V $<$ 30°

[2] Personal communication.

The same authors also find the orientation of their diopsidic lamellae to be parallel to 100. Therefore, if a of the orthopyroxene is brought parallel to the K-axis of the universal stage, the mineral grain should be uniformly dark, and should remain so on tilting around K.

This simple test was applied to a number of crystals, but uniform darkness was never attained. The intergrowth has therefore more than one, and probably three, orientations. This finds some confirmation in the results of Nel (1940) who records an association of three different orientations in the lamellae of the Bushveld orthopyroxene.

The authors consider then that, for hypabyssal rocks, the term " graphic intergrowth " describes the structure best, for the resemblance to the familiar intergrowth of quartz and alkali-feldspar is striking.

They are of the opinion that the intergrowth is due to unmixing during a range of compositions from Of_{25}–Of_{30}. The excess lime is precipitated as hypersthene-augite, which enters into a graphic intergrowth with the orthopyroxene host. Finally, they concur with the views expressed by Hess and Phillips that the relatively imperfect intergrowth in dolerites is due to more rapid cooling.

(2) It was attempted to locate the level in the sill, where orthopyroxene gives place to early pigeonite. Examination of series of sections gave the approximate location of this boundary as indicated in Text-fig. 1. It is noteworthy that the boundary line follows the stoped sedimentary blocks and remains everywhere at 1/3 (from above) of the total thickness of the sill.

INTERSTITIAL MICROPEGMATITE OR MESOSTASIS

Everywhere in the dolerite a graphic intergrowth of quartz and alkali-feldspar is found interstitially, except in the series H_{16}–H_{18} where a mesostasis is developed. The latter is probably due to quicker cooling, caused by the presence of the stoped sedimentary xenolith.

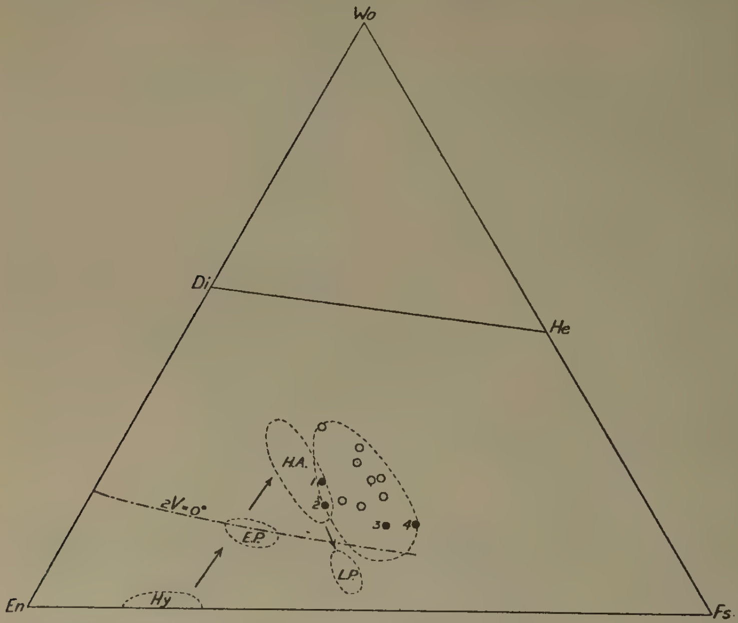
The percentage of micropegmatite varies between 3 and 11 in the different sections, but shows a general tendency to increase upwards. The felspar of the intergrowth is generally altered and cloudy, but there seems to be little doubt that it is a soda-orthoclase of low axial angle.

The accessory minerals, particularly apatite and iron ore, appear to be concentrated in the micropegmatite, which testifies to their later crystallization.

Accessory Minerals

Titaniferous magnetite occurs in varying, but always small, amounts throughout the sill as irregular skeletal masses up to 1 mm. in diameter.

Brown and green biotite occur as reaction products of pyroxene



TEXT-FIG. 2.—Triangular diagram of normative and modal pyroxenes of the Karroo dolerites.

Hy. : orthopyroxene.
E.P. : early pigeonite.
H.A. : hypersthene augite.
L.P. : late pigeonite.
● 1 : dolerite Downes Mountain
● 2 : dolerite Hangnest
● 3 : contact basalt Hangnest
● 4 : dolerite pegmatite Hangnest
⊙ : other Karroo dolerites
} - - - - normative pyroxenes.
Course of crystallization indicated by arrows.

and iron-ore. Green biotite evidently is a zonal modification of the brown as it often forms margins round the latter.

brown biotite γ : 1·667
pleochroism $\left\{\begin{array}{l}\gamma : \text{golden brown} \\ \alpha : \text{golden yellow}\end{array}\right.$
green biotite γ : 1·662
pleochroism $\left\{\begin{array}{l}\gamma : \text{dark green} \\ \alpha : \text{pale greenish-yellow}\end{array}\right.$

Small scraps of a very dark brown biotite are sometimes found distributed through patches of micropegmatite. This is probably the last, iron-rich biotite to crystallize.

Slender needles of apatite are ubiquitous and occur solely in the interstitial micropegmatite.

MODES

Several modes were determined with the Dollar integrating stage and are given in Table IV.

In Table IV a general though by no means regular increase of micropegmatite upwards may be observed. The resemblance in mineral composition between the dolerites of Hangnest and Downes Mountain is striking.

Note

A fine-grained dolerite was found some distance above a hornfels xenolith broken off from the lower stoped block (H_{35}). In it phenocrysts of bronzite (up to 1·2 mm.) and plagioclase (up to 1·5 mm.) are embedded in a fine-grained groundmass consisting of plagioclase (av. 0·4 mm.) and granular clinopyroxene (av. 0·2 mm.), together with very little micropegmatite. The mode shows clearly its abnormal nature and no adequate explanation can be offered for its occurrence.

A chemical analysis was made of a coarse-grained dolerite from the centre of the sill (H_{33}). The results are given in Table VI, where the analyses of Downes Mountain and Umhlatuzi are reproduced for comparison.

COURSE OF CRYSTALLIZATION

In the dolerite again all the evidence points towards the simultaneous crystallization of plagioclase and pyroxene. The authors discussed the course of crystallization of a similar dolerite at Downes Mountain (1940) in detail and a summary will therefore suffice for this paper.

The first plagioclase to crystallize was acid bytownite, which, by continuous and incomplete reaction with the magma, was followed by more and more acid plagioclase.

TABLE III

Pyroxene	γ	α	$\gamma \wedge c$	2V	Orientation of Optic Axial Plane	Av. Comp. (Deer + Wager, 1938)	Occurrence	Properties	Remarks
1. Bronzite	1·687		0°	78° (— ve.)	⊥(010)	Of_{17}	Lower two-thirds of sill. Early crystallization often forming cores to mantles of (3), rarely shells of (2).	Prismatic crystals, elongated along c. when surrounded by (3), cleavage traces pass undisturbed through both core and mantle. Margins against (3) often frayed. b and c axes of (1) and (3) coincide. Often zonal—2Vα: 73°–63°	More zonal crystals show marginal graphic intergrowth with (3). (See text.) Av. size: 2·5 mm. Max. size: 1·2 mm.
2. Early Pigeonite	1·700	1·677	40°	5°	⊥(010)	Wo_{14} En_{61} Fs_{25}	Upper third of sill crystals of early crystallization. Antipathetic to (1). Forms cores to margins of (3). Average 30 per cent of total pyroxene.	Colourless, prismatic crystals generally without cleavage. Markedly elongated along c. Sometimes curved. Surrounded by (3) in crystallographic continuity, γ of (2) and (3) coincides. Elongated crystals may show marked cross fractures.	Thought to be the product of completed reaction between magma and bronzite. Av. size: 1·2 × 0·45 mm. Max. size: 3·0 × 0·6 mm. Av. elongation: 4. Max. elongation: 30.

augite.	1·718	1·694				En_{46} Fs_{27}	sill. Follows (1) and (2) in crystallization. Occurs as subphitic plates or as mantles surrounding cores of (1) and (2).	decreasing, and the refractive indices increasing, towards the margins. Colour pale greenish-brown or purplish - brown increasing towards the margins.	sional. Av. diam. : 1·0 mm. Twinning simple but not common.
4. Late Pigeonite	1·722–1·726	1·697–1·701	35°–30°	13°–19°	⊥(010)	Wo_6 En_{50} Fs_{44}	Mainly in centre of sill. Rare. Last pyroxene to crystallize as extreme margins to (3).	Margins are in crystallographic continuity with (3). Colour: pale brownish - green cleavages well - developed zonal; 2V increases towards extreme margin.	

TABLE IV

Height above lower contact (feet)	H_{39} 30	H_{112} 100	H_{32} 150	H_{30} 208	H_{28} 250	H_{33} 290	H_{107} 290	H_{106} 425	H_{105} 460	H_{17} 485	Average Hangnest (not including H_{30})	Average Downes Mountain
Plagioclase	45·4	47·6	49·8	46·5	47·2	47·8	48·2	45·2	42·9	40·7	46·8	47·0
Pyroxene	45·4	44·2	40·6	50·2	42·2	43·8	42·7	42·7	41·6	42·7	42·9	42·7
Iron ore	2·3	3·7	4·3	3·2	3·2	2·3	3·0	3·6	3·7	4·2	3·3	2·9
Biotite	·7	·8	·3	—	·4	·8	·4	2·0	1·0	·5	·8	·4
Micropegmatite	6·2	3·7	5·0	1·1	7·0	5·3	5·7	6·5	10·8	—	6·3	7·0
Mesostasis	—	—	—	—	—	—	—	—	—	11·9	—	—

The course of crystallization of the pyroxenes is indicated provisionally on the triangular diagram, in which the normative pyroxenes of Karroo analyses (some of which unpublished) are also plotted. It is to be noted that the first half of the diagram agrees closely with the course of crystallization in dolerites as given by Holmes for the Whin Sill (1928), Kuno (1933), and others. All these writers accept the discontinuous reaction series hypersthene → early pigeonite → hypersthene-augite : that is, a course of crystallization tending towards hedenbergite. The second half of the diagram, indicating a turn in the course of crystallization towards $FeSiO_3$, is less certain, being contrary to previous accounts, though Scholtz (13) records the presence of identical late ferriferous pigeonite at Insizwa. The inferences which may be drawn from the diagram, and also the reasons for the several discontinuities, are not yet fully understood and are undergoing further study.

The crystallization of plagioclase and pyroxene was followed by the formation of a graphic intergrowth of quartz and soda-orthoclase within the crystal framework, this being accompanied by the crystallization of iron ore and apatite. Biotite was precipitated last. The late precipitation of iron ore testifies to the high volatile content of the magma (Phemister, 1934).

GRAVITATIONAL DIFFERENTIATION

The almost complete lack of crystal-settling in the 500 ft. Hangnest sill is noteworthy. Pyroxene commenced crystallization at an early stage and continued to form over a considerable period. One would, therefore, expect some settling to have taken place.

Crystal settling in general appears to be prevented by the following factors :—

(1) high viscosity of the magma
(2) small size of crystals
(3) crystal interference.

The first two factors cannot have been very effective at Hangnest. First, the ability of the magma to react with the siltstone gives abundant evidence of richness in volatiles and therefore probably of low viscosity. Second the grain-size of the Hangnest sill is as great as that of some highly differentiated bodies of basaltic composition.

At Hangnest all the evidence points to the fact that elongation prevailed in the early crystallizing minerals ; pyroxenes as well as plagioclases. Growth along the *c*-axis seems to have outpaced outgrowth along the *a*- and *b*-axes. Stokes's law applies to spherical bodies only, and crystals which are markedly elongated will not settle so rapidly as granular crystals of the same volume. Moreover elongated crystals are much more subject to mutual interference. The explanation for the rather conspicuous lack of gravitational differentiation in the Hangnest sill must therefore be sought in the elongation of the early crystallizing minerals.

The increase of micropegmatite upwards has already been commented upon. In the Downes Mountain sill a similar tendency was observed, and upward migration of micropegmatite seems to be general in sills of that mineralogy. It is probably associated with a slight upward filtration of volatiles. As might be expected we find evidence of free growth in the upper dolerites richest in micropegmatite : the grain size is coarser, the constituent minerals are considerably elongated and sometimes markedly curved. Finally hypersthene-augite often shows basal striations and sahlite structure, while biotite is more abundant than in the lower dolerites.

DOLERITE-PEGMATITE

The pegmatitic segregations are characterized by much coarser grain size, and their texture is definitely gabbroic. In thin section the rock consists of plagioclase, pyroxene, and micropegmatite, iron ore, brown and green hornblende, biotite, and apatite forming the accessories. The plagioclase (An_{50}) is tabular, moderately zonal, and twinned on albite, Carlsbad, and pericline laws. Its average elongation is 3 ; maximum 6.

The bulk of the pyroxene is hypersthene-augite ($2V = 50°$), but in addition some iron-rich pigeonite occurs. The pyroxene is generally idiomorphic and elongated, though graphic intergrowths of pyroxene and plagioclase are also seen. Marginal alteration of the pyroxene, probably in the hydrothermal stage, has given rise to a parallel intergrowth of brown and green amphibole. The abundant matrix consists of grains of quartz and coarse micropegmatite, together with iron ore, biotite, and needles of apatite.

The pegmatitic patches and schlieren are probably caused, as in so many other sills, by segregation of volatile-rich fractions of the magma.

A chemical analysis of the pegmatite H_{40} is given in Table VI. The mode of this rock is :—

plagioclase .	31·3	biotite . . .	1·0
pyroxene .	27·8	iron ore . .	4·9
hornblende .	5·8	micropegmatite .	29·2

Phemister (1934) argues on theoretical grounds that in such rocks the $Fe_2O_3 : FeO$ ratio should be greater than in the normal rocks. When the ratio was, however, calculated for the well known pegmatites and dolerites of Goose Creek, the Whin Sill, the Palisade sill, and finally for the Hangnest sill, it was found that only in the last case was there an increase in the $Fe_2O_3 : FeO$ ratio. In all other examples the ratio is actually lower in the pegmatites than in the corresponding dolerites. Generally, however, the $FeO : MgO$ ratio, and also the $Fe_2O_3 + FeO : MgO$ ratio are higher in the pegmatites than in the dolerites, as are the total alkalies (Table V).

TABLE V

	$\frac{Fe_2O_3}{FeO}$	$\frac{FeO}{MgO}$	$\frac{FeO + Fe_2O_3}{MgO}$	$Fe_2O_3 + FeO$	Tot. Alk.
Pegmatite Hangnest .	0·311	2·59	3·36	10·77	3·50
Dolerite Hangnest .	0·111	1·17	1·30	9·83	2·58
Pegmatite Palisade .	0·259	2·95	3·71	9·58	4·81
Dolerite Palisade .	0·317	2·76	3·63	12·62	3·88
Pegmatite Whin Sill	0·213	3·70	4·50	12·35	4·12
Dolerite Whin Sill .	0·395	1·66	2·32	13·77	3·74
Pegmatite Goose Creek	0·013	2·21	2·24	12·16	3·48
Dolerite Goose Creek	0·085	1·53	1·66	12·28	3·04

It will be noticed that there is a slight amount of absolute enrichment in $Fe_2O_3 + FeO$ in the Hangnest pegmatite, this being compatible with the mild fractionation in the sill.

REACTION PHENOMENA WITH BEAUFORT SEDIMENT

The reaction phenomena between sediment and dolerite may be divided into three groups, viz. :—

(1) Mobilization of the sediment and injection into the dolerite, resulting in the production of rheomorphic veins and dolerite breccia.

(2) Metasomatism of the sediment induced by permeating magmatic emanations with the production of reaction-granophyre.

(3) Mechanical mixing of sediment and dolerite and reaction of sediment with dolerite magma.

The first two groups of phenomena are the most common in Karroo dolerite sills and the second group in particular is important. Examination of a number of thick sills has led the authors to believe that reaction-granophyres are by no means rare in the Karroo and that all these rocks resemble each other rather closely. This again is not unusual as both the dolerites and the associated Karroo sediments are usually very uniform in composition.

THE SEDIMENT

The sediments adjacent to the Hangnest sill consist of an alternating succession of yellowish-grey argillaceous siltstone interbedded with thinner layers of blue shales. The authors have not much to add to the detailed description of equivalent sediments given by Scholtz (1937). In thin section the sediment consists of varying amounts of small angular quartz grains, chloritic aggregates, flakes of biotite and muscovite, and some clastic grains of acid plagioclase and potash-feldspar. Among the heavy minerals a white or pale pink garnet, magnetite, zircon, apatite, and tourmaline were recognized. The matrix consists of varying amounts of argillaceous material. A chemical analysis of a typical siltstone is given in Table VI.

MOBILIZATION AND INJECTION OF SEDIMENT

Rheomorphic veins in Karroo dolerites have been noted by Mountain (1936) and the authors (1940). The Hangnest veins are identical with those described at Downes Mountain.

As a rule in Karroo dolerite sills rheomorphic hornfels veins are more common than the equivalent siltstone veins, the latter sediment being more liable to react with the magma after mobilization. The hornfels, upon mobilization, was thoroughly recrystallized and commonly consists of a mosaic of quartz, fine micropegmatite, and granules of clinopyroxene, together with chlorite, brown biotite, and magnetite. The rheomorphic veins emerging from either the upper or lower contact of sills, were injected into completely solid contact basalt. The only effects visible are a development of poikilitc brown biotite in the contact basalt and the deposition of abundant minute granules of iron ore along the margins of the hornfels veins. Both minerals are presumably of hydrothermal formation. The rheomorphic veins themselves often show flow structures, testifying to their plastic nature during injection. The veins vary in width from 0·05–4 inches, but are usually 0·5–1 inch wide.

The miniature breccia (H_{23}) found at Hangnest belongs to the same category. Here the mobilized sediment invaded the dolerite *en masse* over a short distance and brecciated the latter, which was at the time completely solid.

TABLE VI

CHEMICAL ANALYSES

	I	II	A	B	C	D	E	F	III	G	H	I	IV	V
SiO_2 .	52·52	53·03	52·25	53·21	53·29	50·52	51·56	51·91	57·36	49·70	52·94	52·50	69·26	65·14
TiO_2 .	1·14	1·06	1·10	1·73	1·14	2·39	1·48	1·25	2·54	2·70	2·32	1·36	·38	·46
Al_2O_3 .	16·03	14·90	14·60	13·95	13·20	13·76	13·81	15·31	14·38	15·64	14·80	18·28	14·82	14·92
Fe_2O_3 .	0·37	0·98	0·84	1·24	1·14	3·87	0·96	0·98	2·54	2·42	0·16	1·97	0·81	1·18
FeO .	9·12	8·85	9·89	8·93	10·72	8·50	11·32	9·31	8·23	11·35	12·00	7·61	3·89	5·04
MnO .	0·08	0·13	0·45	0·23	0·15	0·16	0·19	0·08	0·13	0·14	0·24	0·09	0·12	0·04
MgO .	5·14	7·32	6·95	7·19	7·78	5·42	7·40	7·52	3·17	3·06	5·42	2·58	1·88	2·17
CaO .	8·89	9·40	9·71	8·95	6·81	9·09	10·08	9·71	7·18	8·03	8·32	9·34	1·29	2·49
Na_2O .	2·01	2·02	2·21	2·65	2·38	2·42	2·08	2·30	1·96	2·90	1·98	3·78	1·78	2·70
K_2O .	0·82	0·72	0·96	1·13	1·40	0·96	0·96	0·79	1·54	1·22	1·50	1·03	3·42	3·38
H_2O+ .	1·98	0·74	0·71	0·49	1·22	1·51	—	0·93	1·08	1·20	—	1·06	2·23	1·96
H_2O- .	0·80	0·35	0·32	0·22	0·71	0·76	—	0·15	0·58	0·70	—	0·50	0·22	0·39
CO_2 .	0·66	0·20	—	—	—	—	—	—	0·14	tr.	—	—	—	tr.
P_2O_5 .	0·21	0·19	0·22	0·21	0·08	0·26	0·16	0·18	0·31	0·55	0·28	0·06	0·16	0·20
Total .	99·77	99·89	100·21	100·13	100·02	100·31	100·00	100·42	99·77	99·61	99·96	100·16	100·14	100·07

Rheomorphic veins, originating from xenoliths in the centre of sills or some distance away from either contact, were injected under slightly different conditions. In this case the dolerite was not yet completely solidified, although a crystal framework of plagioclase and pyroxene had already been formed. The injection of mobilized material presumably took place just before and during the formation of micropegmatite within this framework. The veins do not show sharp margins against the dolerite and some of the mobilized sediment was introduced interstitially within the crystal framework of the dolerite. Occasionally evidence of some reaction between sediment and dolerite may be detected in this case (see also group iii), but this is rare.

METASOMATISM OF SILTSTONE

Microscopically the reaction-granophyre (H_{13-14}) consists of abundant micropegmatite, slender elongated plagioclase laths and elongated prisms of clinopyroxene altered to a greenish-yellow serpentine. Iron ore, brown biotite, and apatite are accessories. The plagioclase has an average elongation of 4–6, and its average composition is An_{35} (β : 1·546). The laths are twinned mainly on the Carlsbad and rarely on the albite law. Zoning is common and compositions up to An_{45} were found. Alteration to kaolinite and sericite is widespread. The pyroxene is completely altered to serpentine, but comparison with similar and fresher granophyres from other localities shows that the original pyroxene consisted of elongated cores of pigeonite, surrounded by margins of hypersthene-augite.

I. Hangnest, basalt upper contact (H_{16}). Analyst F. Herdsman.
II. Hangnest, dolerite 290 feet above lower contact (H_{33}). Analyst F. Herdsman.
A. Average Karroo Dolerite. Quoted from Daly and Barth (1930).
B. Dolerite, Downes Mountain. Quoted from Walker and Poldervaart (1940). Analyst A. J. Hall.
C. Dolerite at Umhlatuzi Crossing, Natal. Quoted from G. T. Prior, *Ann. Natal Museum*, 2, 1910, 149. Analyst G. T. Prior.
D. Average Whin Sill magma. Quoted from Holmes and Harwood (1928).
E. Dolerite, Goose Creek. Quoted from E. V. Shannon, *U.S. Nat. Museum*, pr. vol. 66, 1924, 27–8. Analyst E. V. Shannon.
F. Average undifferentiated palisade magma. Quoted from Walker (1940).
III. Hangnest, dolerite pegmatite (H_{40}). Analyst, F. Herdsman.
G. Dolerite-pegmatite, Whin Sill. Quoted from S. I. Tomkeieff, *Min. Mag.*, 22, 1929, 100–120. Analyst, F. Herdsman.
H. Dolerite-pegmatite, Goose Creek. Quoted from Shannon (1924). Analyst, E. V. Shannon.
I. Dolerite-pegmatite, Palisade. Quoted from Walker (1940). Analyst, F. Herdsman.
IV. Hangnest, siltstone upper contact (H_{19}). Analyst, F. Herdsman.
V. Hangnest, reaction-granophyre (H_{13}). Analyst, F. Herdsman.

The grain size may vary considerably but a tendency towards increase in grain upwards is generally found in the exposures. An analysis of the granophyre is given in the Table VI. The mode of this rock is :—

plagioclase	14	biotite	2
pyroxene	27	micropegmatite	53
iron ore	4		

From a comparison of the analyses of dolerite, granophyre, and siltstone the following facts emerge :—

(*a*) Na_2O is higher in the granophyre than in either the dolerite or the siltstone.

(*b*) K_2O is the same in the granophyre and the siltstone and in both rocks higher than in the dolerite.

(*c*) In the granophyre the values of CaO, total iron oxide, and MgO are intermediate between those of the dolerite and the sediment.

Thus in the granophyre there has been a marked addition of Na_2O from the magma and a lesser addition of the cafemic oxides from the same source. The analyses together with the field evidence indicate that :—

(i) the granophyre is the product of metasomatism brought about by magmatic emanations and not the result of mechanical mixing and chemical reaction between dolerite magma and siltstone.

(ii) the magmatic emanations were released over a prolonged period, and probably reached a culmination during the later stages of crystallization of the dolerite.

In the dolerite sill of Rietkop, which is at present undergoing investigation, a persistent horizontal stratum of unaltered siltstone nodules was found in the centre of a very similar exposure of reaction-granophyre. Moreover the divisional planes of the Hangnest granophyre correspond closely with those of the stoped siltstone block, indicating that the metasomatic rock was formed in place without notable mobilization.

The rather peculiar granitic composition of the Karroo siltstone required only slight magmatic addition for the formation of a reaction-granophyre, probably not very different in chemical composition from the more extreme products of crystal fractionation, but with a very characteristic texture and mineralogy. More data are necessary to draw further conclusions as to the nature of the process and the authors intend to deal with the whole problem in a future paper, when the investigation of certain other sills has been completed.

MECHANICAL MIXING AND REACTION WITH DOLERITE

Two different reaction phenomena observed at Hangnest fall under this heading. In the one case the sediment is the rather impure Beaufort siltstone, in the other case the argillaceous hornfels was affected.

The arenaceous veins (H_{26-27}), found at approximately the centre of the sill, were observed to have reacted with the dolerite to some extent. The vein material represents the metamorphosed Beaufort siltstone and can be divided into two parts, viz. felsic : quartz, alkali feldspar, and a little acid plagioclase ; and mafic : biotite, chlorite, and granular clinopyroxene, presumably diopsidic. In the first instance this mobilized, plastic material seems to have been introduced in the interstices of the dolerite by a process of mechanical mixing. We thus find interstitial patches of metamorphosed sediment within a framework of basic labradorite and hypersthene-augite.

In the second instance there is evidence of reaction between this interstitial material and the dolerite. The felsic part, being late in the reaction series, was dissolved to crystallize together with the magmatic residuum as quartz, micropegmatite, and small stout laths of medium plagioclase. The mafic part, consisting of material earlier in the reaction series, reacted with the pyroxene of the dolerite and produced a more lime-rich pyroxene in the form of marginal granules. Thus we find that the interstitial patches are clear of most mafic minerals, whereas the larger pyroxenes are marginally granulated. The centres of larger plagioclase individuals are clouded with small rods of an indeterminable mineral which, according to MacGregor (1931), is an indication of mild contact metamorphism. In addition the interstices are riddled with abundant apatite needles.

The reaction product of argillaceous hornfels and partly solidified dolerite (H_{29}) shows a slightly different state of affairs. Here apparently the sediment had an excess of Al_2O_3. As in the former case the felsic part of the sediment recrystallized interstitially to form micropegmatite, quartz, and small, broad laths of clear medium plagioclase. The mafic part, however, attacked the pyroxene of the crystal framework and produced instead a non-pleochroic, iron-rich hypersthene (Of_{63}) with $2V\alpha : 55^\circ$ and $\gamma : 1{\cdot}715$.

Read's study of the Haddo House complex (1935) explains the mechanism involved. The sediment was deficient in CaO though rich in Al_2O_3 and FeO. It therefore reacted with the hypersthene-augite of the dolerite to produce an iron-rich orthopyroxene, whereas the lime liberated combined with alumina and silica to form plagioclase. Here again the larger plagioclase laths are cloudy except for their extreme margins, while the small laths occupying the interstices are clear. Apatite is absent from all our slides. A mode of the mixed rock shows the following results.

plagioclase .	42·3	biotite . . .	1·6
pyroxene .	31·8	interstitial material .	23·4
iron ore . .	·9		

The chemical analyses of the Hangnest rocks are combined in Table VI together with other analyses for comparison.

TABLE VII

NORMS

		I	II	III	IV	V
Quartz . . .		8·0	5·5	17·7	38·1	24·8
Orthoclase . . .		5·0	3·9	8·9	20·0	20·0
Albite		16·8	16·2	16·8	15·2	23·0
Anorthite . . .		32·2	29·8	25·9	5·6	11·7
Corundum . . .		—	—	—	6·1	2·4
Diopside	Wo . .	2·8	6·4	3·3	—	—
	En . .	1·3	3·5	1·4	—	—
	Fs . .	1·5	2·6	1·8	—	—
Hypersthene	En . .	11·5	14·8	6·5	4·7	5·3
	Fs . .	13·1	11·4	9·2	5·8	7·4
Ilmenite . . .		2·1	2·1	2·1	·8	·8
Magnetite . . .		·9	1·4	3·7	1·2	1·9
Apatite . . .		·3	·3	·7	·3	·3
$CaCO_3$ . . .		1·6	·5	·2	—	—
H_2O		2·8	1·1	1·7	2·5	2·4
Total . . .		99·7	99·5	100·1	100·3	100·1

CONCLUSIONS

The following are the chief points regarded as established by the investigation.

(1) The 500-ft. sill of Hangnest consists of coarse dolerite, the lower two-thirds of which carry orthopyroxene.

(2) Hypersthene-augite is always present and forms a graphic intergrowth with orthopyroxene. Pigeonite of early or late crystallization is also found ; the former being antipathetic to bronzite.

(3) There are no signs of crystallization-differentiation in the sill apart from the occurrence of schlieren of dolerite-pegmatite and a slight downward increase in the proportion of pyroxene, which is offset by an upward increase in the proportion of micropegmatite.

(4) The lack of crystal settling seems due to crystal interference emphasized by the elongated habit of the early pyroxene.

(5) The composition of the associated Karroo sediments was such that they underwent mobilization easily, this being followed by rheomorphic injection with sufficient force to brecciate the contact basalt of the sill.

(6) The rheomorphic veins nearer the centre may show mechanical mixing and reaction with the adjacent partly crystallized dolerite resulting in a rock rich in micropegmatite and small laths of interstitial andesine.

(7) A large xenolithic block of siltstone has undergone metasomatism with addition of soda and to a lesser degree of cafemic bases.

(8) The product of metasomatism is a granophyric rock of very distinctive appearance in the field and of widespread occurrence in the Karroo.

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EXPLANATION OF PLATE VIII

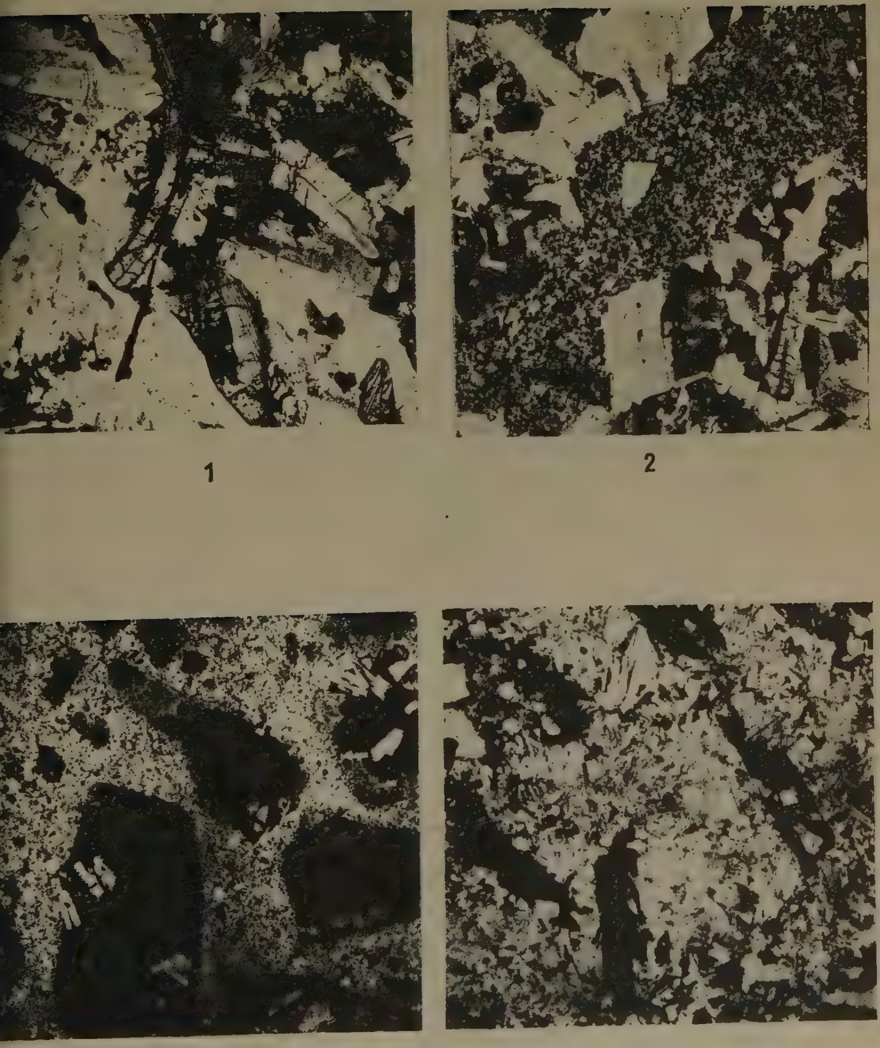
Photomicrographs by ordinary light × 10 diameters.

Fig. 1.—Coarse dolerite from upper part of sill. Shows marked curvature of clinopyroxene.

Fig. 2.—Thin stringer of rheomorphic siltstone invading dolerite. The pyroxene of the dolerite shows marginal granulation.

Fig. 3.—Mobilized siltstone invading and brecciating contact basalt in which microphenocrysts of plagioclase and orthopyroxene are conspicuous.

Fig. 4.—Reaction-granophyre from upper part of sill. Conspicuous prisms of serpentinized clinopyroxene are set in a turbid matrix consisting of andesine, quartz, and micropegmatite.



1 2

3 4

Microphotographs of Rocks from the Hangnest Sill.

The Coal Veins of British Malaya [1]

By J. A. Richardson, Federated Malay States Geological Survey

(PLATES IX—X)

So far as the writer has been able to ascertain, the occurrence in British Malaya of coal in vertical veins, as distinct from coal interbedded with sediments, was first recorded in 1908 by Mr. J. B. Scrivenor, who described an example in a tin mine in alluvium at Siputeh, west of Batu Gajah, Perak.

Since that time, vertical and steeply inclined veins of jet black coal (vitrain) have been discovered in twelve other localities, all in Perak, and none has yet been seen in other parts of Malaya. All these occurrences are now described; details of those not available for study by the writer have been obtained from accounts written by Messrs. J. B. Scrivenor, E. S. Willbourn, F. T. Ingham, J. Drysdale, and G. F. Gripper. The writer wishes to thank Mr. Willbourn for his assistance in preparing this paper. Thanks are also due to Messrs. Malayan Collieries, Limited, who have been good enough to supply seven analyses.

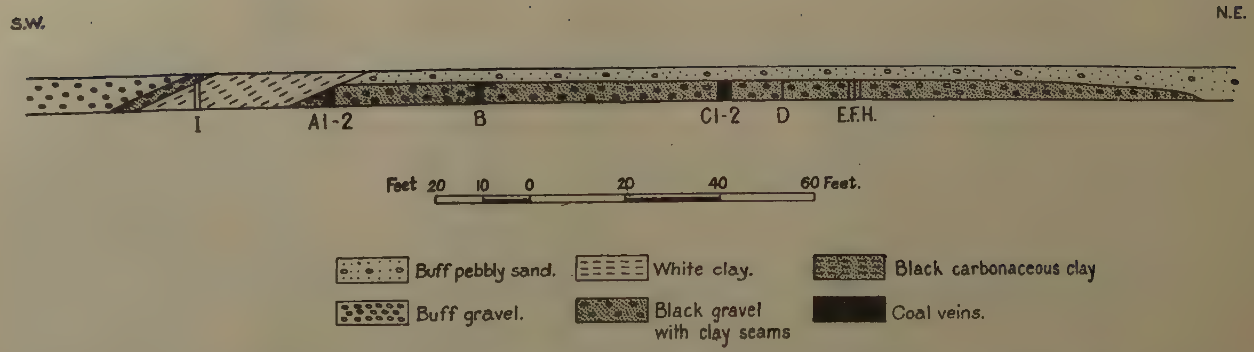
During his visit to Malaya in 1938 Sir Lewis L. Fermor was taken by Dr. Ingham to see coal veins in alluvium near Bidor, and he published a paper, " On Coal Veins in Malaya " (*Geol. Mag.*, lxxvi, No. 905, 1939, 465–472) in which the composition of the coal was compared with that of some Indian vitrains. Sir Lewis says (op. cit., p. 471) :—

> " Comparing these analyses on an ash-free basis with the data for Indian vitrains given on p. 466 it will be seen that the Malayan vitrains have a higher specific gravity and a higher moisture content than any of the Indian vitrains there shown and provide a downward extension to Table VII in the paper cited. It seems appropriate that these Malayan vitrains, as the youngest of all, being of recent age, should have the highest moisture content and consequently the highest specific gravity."

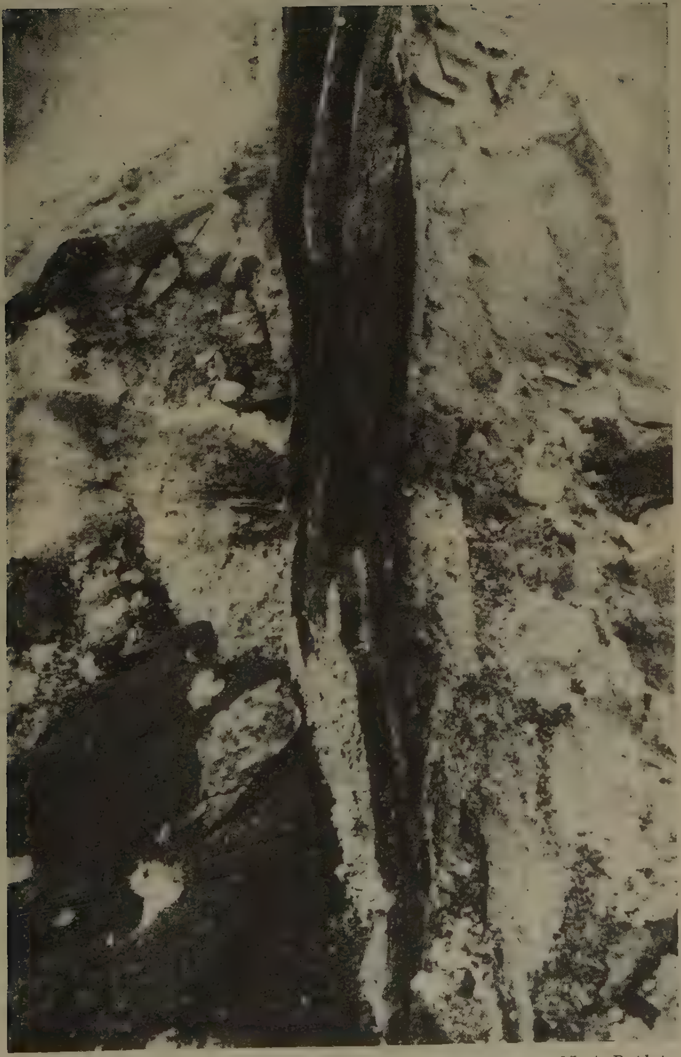
Concerning their origin, he writes (p. 472) :—

> " We are compelled, therefore, to regard these vitrain veins as true veins deposited in their present vertical position. Whether they fill fissures that had opened in the alluvium, or have widened cracks by replacement, is doubtful. The zoning of the veins recalling crustification might be explained on either hypothesis.
>
> " For the source of the coal-forming substance we are entitled to point to the wood in the alluvium, and to assume that organic matter derived therefrom has passed into solution in ground water, presumably as humic acids or related substances, and has been deposited therefrom as the veins we now see. The vitrain itself must be regarded as a gel, as we have seen above, and therefore the deposition was presumably due to gelation of a colloidal solution. The conditions of the ground water were presumably reducing, if we can judge from the bleached condition of the alluvium and the underlying decomposed bed-rock and the absence of all yellow or red tints."

[1] Published by permission of the Director, Geological Survey, Federated Malay States.

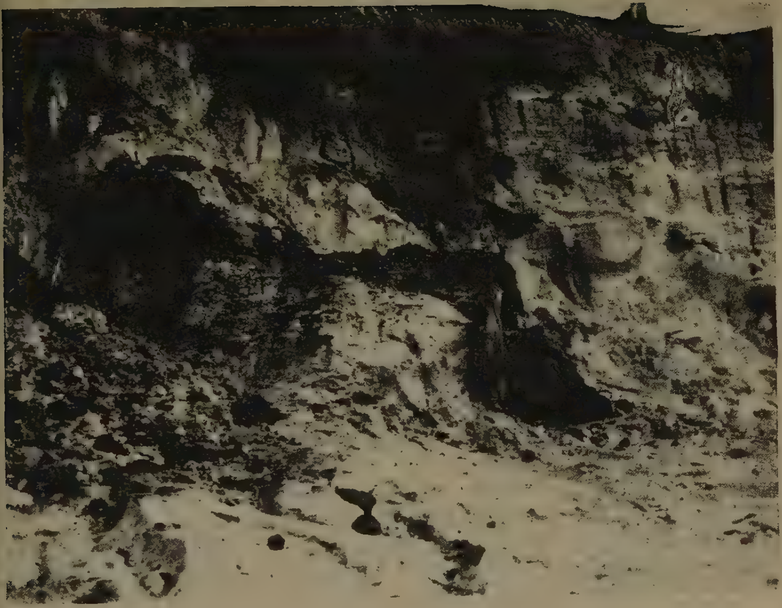


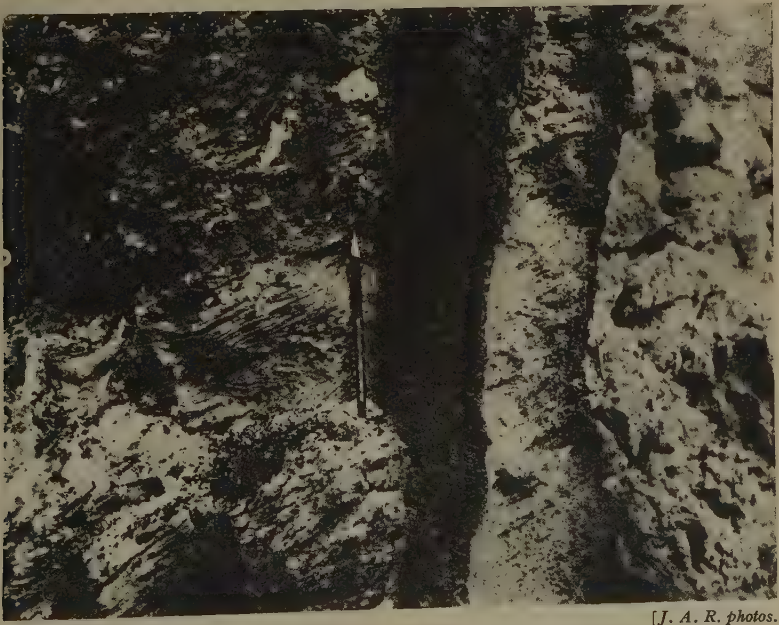
TEXT-FIG. 1.—Diagrammatic section of the Western Wall of the Canal, 1½ miles south-west of Milestone 80½, Ulu Ijok, Perak. It shows the arrangement of the coal veins.



[J. A. R. photo.

HIN FATT KONGSI MINE NO. 2, LOT 3368, BIDOR, PERAK.
Portion of a vertical coal vein in alluvium.





[J. A. R. photos.

HIN FATT KONGSI MINE NO. 2, LOT 3368, BIDOR, PERAK.

FIG. 1.—A vertical coal vein which passes from gravel into bedrock of weathered contorted schist. It is overlain by 10 feet of alluvium.

FIG. 2.—The lower portion of the vein depicted in Fig. 1, showing the crustified

GENERAL DESCRIPTION OF THE COAL VEINS

The coal veins occur in fissures cutting steeply through horizontal or gently-dipping alluvium, and sometimes passing into decomposed bedrock, *and no instance is known of coal layers concordant with the bedding.* The tops of most of the coal veins have been eroded and are now covered by more recent superficial deposits; their lower extremities commonly thin out to knife-edges in alluvium or decayed bedrock.

Analyses (Table III) show this coal to be similar in composition to the Tertiary bedded coals mined by Messrs. Malayan Collieries, Ltd., at Batu Arang, Selangor, so that it would probably be marketable if present in sufficient quantity, but, although some of the veins extend for as much as a hundred yards along their strike, they are always narrow, and none has been found of sufficient width to be of economic value. Most of them range from 1 inch to 6 inches in width; few are as wide as 2 feet. Their extension downwards may be as much as 30 feet; one vein passes through 20 feet of alluvium and penetrates 10 feet into schist. Their margins are well defined, but a colour gradation from the blackness of the coal to the pale tint of the alluvium and bleached schist has been caused by the filtering of carbonaceous material outwards from the veins; the rocks adjacent to coal veins,

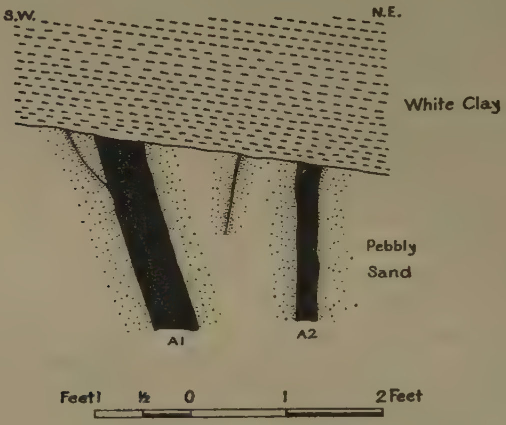
TABLE I

DISTRIBUTION OF COAL VEINS IN PERAK, F.M.S.

Locality	Lot Number	Topo Sheet
A canal in the mukim of Ulu Ijok constructed by the Drainage and Irrigation Department .	—	2 I/16
Hin Fatt Kongsi Mine, No. 1	3355	2 I/14
Hin Fatt Kongsi Mine, No. 2	3368	
Hin Fatt Kongsi Mine (abandoned) . .	1934	
Heng Bee Kongsi Mine (abandoned) . .	3329	
Lai Chak Mine, Semoliang (abandoned) . .	1534	
Semoliang Gold Mine	3354 & 3380	
Allington Hill Estate, near Tapah Road Railway Station	1934	2 I/13
Kamparmalim Estate, Pulau Pisang, Malim Nawar	26170	2 N/9
Kuala Kampar Tin Fields, Limited's Mine, Malim Nawar	20530	
Lee Sang Kongsi Mine, Malim Nawar . .	21486	
Siputeh, Limited's Mine, Siputeh . . .	—	2 M/12
Asam Kumbang, Taiping	1865 & 2039	2 M/3

generally, are stained light brown over a narrow zone, the intensity of discolouration decreasing outwards from them. Lenses of alluvium occur in some of the larger veins.

The coal is banded and crustified. Its lustre varies from adamantine to resinous. It is fairly hard, but brittle and splintery, and it has a sub-conchoidal or conchoidal fracture ; exposed to the atmosphere, it loses moisture and gradually breaks into small angular fragments.



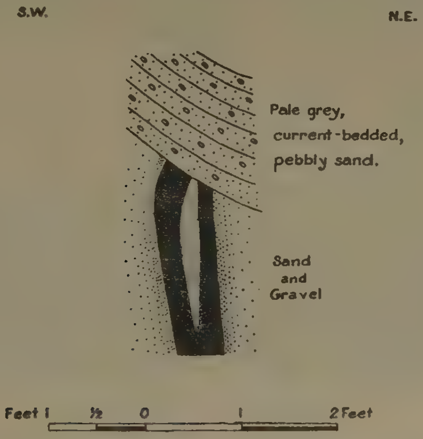
TEXT-FIG. 2.—Vertical section of parts of Veins A 1 and A 2 exposed in the Canal at Ulu Ijok, Perak. Their eroded upper surfaces, shown black, are overlain by white clay.

Discoloration, caused by the seepage of carbonaceous solutions from the veins into the adjacent sand, is depicted by stippling.

Most of the coal is vitrain, but there are thin seams of a soft brown carbonaceous substance also. Under the microscope, the coal has the appearance of a translucent brown gel, and no vegetable structure has been detected in it.

The veins at Ijok, Allington Hill Estate, and Kamparmalim Estate, have been described by Mr. Willbourn in his unpublished field notes ; those at Hin Fatt Kongsi Mine (lot 1934), Heng Bee Kongsi Mine, Lai Chak Mine, Semoliang Gold Mine, and Allington Hill Estate by Dr. Ingham in paragraph 42 of the *Report of the Geological Survey Department* (*F.M.S.*) *for 1936*, paragraphs 79 to 81 of the *Report* for 1937, and on pp. 69 and 70 of *The Geology of the Neighbourhood of Tapah and Telok Anson* ; that at Asam Kumbang by Dr. Ingham in his unpublished field notes ; that at Siputeh by Mr. Scrivenor in paragraphs 16 and 52 of the *Report of the Geological Survey Department* (*F.M.S.*) *for 1908*, on pp. 82 and 83 of *The Geology of Malayan Ore-Deposits*

(Macmillan and Co., Ltd., London, 1928), and on p. 126 of *The Geology of Malaya* (Macmillan and Co., Ltd., 1931); those at Kuala Kampar Tin Fields, Limited's Mine and at the Lee Sang Kongsi Mine by Messrs. Drysdale and Gripper respectively, in letters to the Director, Geological Survey.



TEXT-FIG. 3.—Vertical section of the upper portion of vein B exposed in the Canal at Ulu Ijok, Perak. It has a core of carbonaceous sand enclosed by coal.

DETAILED DESCRIPTION OF THE COAL VEINS

Coal veins are exposed in a canal, 1½ miles south-west of milestone 80½ on the road from Ipoh, in the mukim of Ulu Ijok, Upper Perak, where alluvial clay, sand, and gravel are underlain by Triassic quartzite and shale. Nine coal veins occur here over a length of 170 feet; a tenth is exposed about half a mile south-west of the road. Particulars of the veins are given in Table II, and several are illustrated in Text-figs. 1, 2, 3, and 4. They occupy fissures in alluvium. As their lower limit is nowhere visible, it is unknown whether or not they extend into bedrock; each is terminated, upwards, against current-bedded sand, gravel, or clay. Many are composite, enclosing seams of hard, compact, carbonaceous alluvium (Text-fig. 3).

COAL VEINS IN THE BATANG PADANG DISTRICT, PERAK

Hin Fatt Kongsi Mine No. 1, Bidor

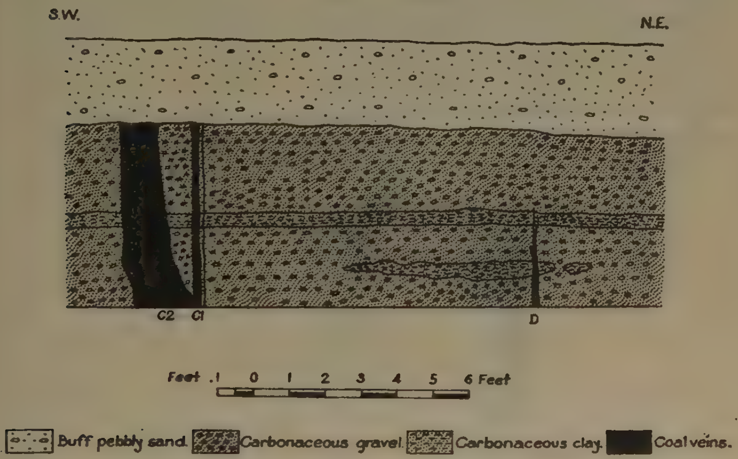
Four veins are exposed in this gravel pump mine where 30 feet of alluvium overlie weathered Permocarboniferous mica-schist bedrock, not appreciably harder than the superficial

TABLE II

PARTICULARS OF THE COAL DYKES EXPOSED IN THE CANAL CONSTRUCTED BY THE DRAINAGE AND IRRIGATION DEPARTMENT, MUKIM OF ULU IJOK, UPPER PERAK, F.M.S.

Vein	Dip of Vein	Direction of dip	Strike of Vein	Width of Vein in inches	Remarks	
A 1	85°	162°	72°	5 to 6	This is a compound vein which widens to 18 inches in the east face of the canal, where a considerable amount of carbonaceous alluvium has been incorporated. Several veinlets of coal, ⅛ inch wide, pass from it out into alluvium (Text-figs. 1 and 2).	
A 2	90°	—	93°	2		
B	90°	—	100°	5 to 7	This is a composite vein in which a central band of hard, carbonaceous alluvium, 2 to 3 inches wide, is enclosed by coal (Text-figs. 1 and 3).	
C 1	90°	—	70°	3	This compound vein is cut by vertical veinlets of vitrain striking eastwards (Text-figs. 1 and 4). The individual coal bands of which this vein is composed do not exceed ½ inch in width (Text-figs. 1 and 4).	The three veins, C 1, C 2, and D, coalesce and, together with included carbonaceous alluvium, they form a vertical band, 5 feet wide, striking 110°, in which there are numerous narrow bands of coal.
C 2	90°	—	70°	18		
D	90°	—	108°	2		
E	85°	South	East	3	It is composed of five vitrain bands, ⅛ inch to ½ inch wide, which alternate with seams of carbonaceous, pebbly sand (Text-fig. 1).	Veins E and F are cut by vein H (Text-fig. 1).
F	90°	—	108°	1 to 1½	This vein resembles vein E.	
G	85°	155°	65°	7½ to 9	It is composed of vitrain bands, as much as 1 inch in width, which alternate with carbonaceous, pebbly sand.	
H	90°	—	156°	2 to 4	This vein coalesces with vein G, and cuts across veins E and F (Text-fig. 1).	
I	90°	—	92°	2	This consists of a few thin stringers of vitrain which cut vertically through a band of white, kaolin-like clay (Text-fig. 1).	

deposits. Two of the veins, 1 or 2 inches wide, strike eastwards and penetrate vertically through 15 feet of alluvium and down into bedrock; their eroded upper surfaces are overlain by 15 feet of clay, sand, and gravel. The two remaining veins differ from those described above in that the coal occupies only the upper portion of the fissures, the lower parts of which are merely "peat-stained" cracks containing no coal (Text-fig. 5).



Text-fig. 4.—Vertical section of veins C 1, C 2, and D, exposed in the Canal at Ulu Ijok, Perak.

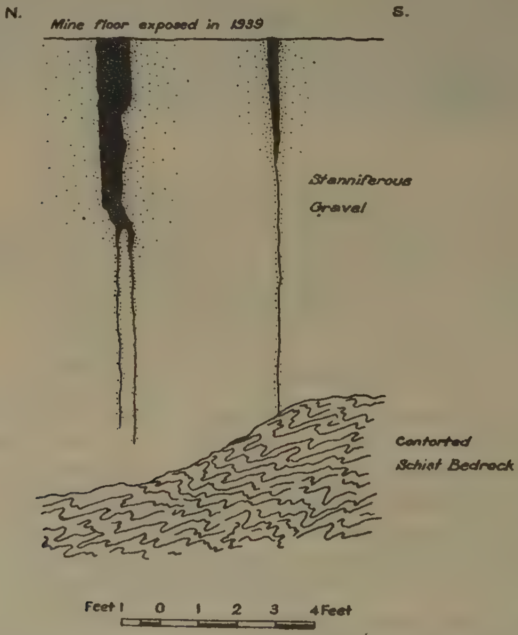
Hin Fatt Kongsi Mine No. 2, Bidor

Six coal veins are visible in this mine where 30 feet of alluvium overlie soft, decomposed mica-schist. A vein (Text-fig. 6), exposed near the sump, strikes north-west, and, after passing upwards from schist through 20 feet of alluvium, is terminated against sand, gravel, and clay. Another vein (Plate IX), striking 345°, in the south-west corner of the mine, is overlain by 10 feet of alluvium. It cuts vertically downwards through 20 feet of clay, sand, and gravel, including a log of wood, and penetrates the schist for at least a foot. Its width is 1 foot in the alluvium where it consists of bands of vitrain alternating with seams of clay, sand, and gravel, but only 1 inch in bedrock where it is composed of solid coal. Another vertical vein (Plate X Text-figs. 1 and 2), a foot wide, in the northern face of the opencast, strikes 320°. It penetrates for at least 6 feet into bedrock and extends upwards through 6 feet of gravel, terminating against a band of peaty clay overlain by alluvium.

Other Occurrences in the Batang Padang District

Vertical veins occurred in the Hin Fatt Kongsi Mine on lot 1934. One of them, bearing 78°, had subdivided into branches, 1 or 2 inches wide, striking between 40° and 130°.

Several vertical veins, generally bearing 38°, were exposed in the Heng Bee Kongsi Mine on lot 3329. Some extended into schist for as much as 12 feet; a few cut quartz veins in the bedrock, while another passed through the bark of a log of wood enclosed in a layer of peaty alluvium. The widest vein was 2 feet, but the majority were only from 1 inch to 4 inches thick, becoming narrower in depth until, in schist, they were no thicker than a knife edge. Some could be traced for 100 yards along their strike.

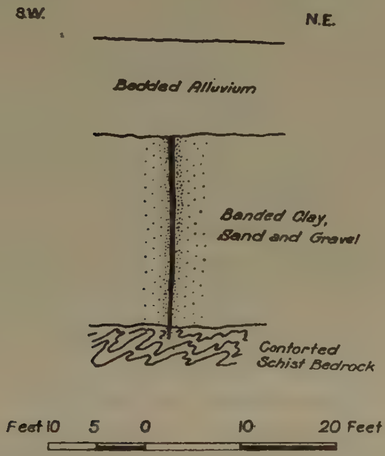


TEXT-FIG. 5.—Vertical sections of Coal Veins in Hin Fatt Kongsi Mine No. 2, Lot 3355, Bidor, Perak. The coal shown black, ends nearly 7 feet above bedrock, although "peat-stained" cracks continue downwards from it. Discoloration, due to the seepage of carbonaceous material into the adjacent gravel, is indicated by stippling.

At the Lai Chak Mine, lot 1534, Semoliang, there were vertical coal veins striking 320°, and varying in width from 1 to 4 inches; three analyses are quoted in Table III.

Coal veins were visible formerly at the Semoliang Gold Mine on lots 3345 and 3380.

Another coal vein is exposed on lot 1934, Allington Hill Estate, near Tapah Road Railway Station. It is some 2 inches wide, it strikes 320°, and it cuts vertically through 6 feet of black or dark brown sandy gravel cemented by carbonaceous material; its lower extremity is not visible. An analysis is given in Table III.



TEXT-FIG. 6.—Vertical section of a vein in Hin Fatt Kongsi Mine No. 2, Lot 3368, Bidor, Perak. Discoloration, caused by the seepage outwards of carbonaceous material, affects both the schist and alluvium traversed by the veins.

Occurrences in the Kinta District

Coal veins have been recorded from three localities in South Kinta. One, in a recent deposit of peaty sand on Kamparmalim Estate, lot 26170, Pulau Pisang, 2 miles north of Malim Nawar, was described by Mr. Willbourn as a vein of black coaly matter, 4 to 5 inches wide, dipping 85° towards 207°; it had the superficial appearance of coal, but would not burn freely, and left a great deal of ash after ignition.

Mr. Drysdale described three similar veins exposed in a mine worked by Messrs. Kuala Kampar Tin Fields, Limited, on lot 20530, Malim Nawar. They were striking northwards, and varied in width from 4 to 18 inches, cutting almost vertically through hard clay, sand, and stanniferous gravel. Where thev were thinnest they consisted of solid coal; where they were widest they contained also lenses of hard clay.

Mr. Gripper has reported that coal veins occur in the Lee Sang Kongsi Mine on lot 21486, situated approximately 1 mile from those described above.

The only other occurrence known in the Kinta District was that described in 1908 by Mr. Scrivenor (*Report of the Geological Survey Department, Federated Malay States*, 1908, paragraphs 16 and 52) at Messrs. Siputeh, Limited's tin mine at Siputeh. Here, carbonaceous material formed a network of veins, either brown or black, crossing each other in sandy alluvium. The material in some of the veins was soft, like putty, in others hard, and much of the hard, black substance had a lustrous surface, did not soil the fingers, and had a fracture like that of cannel coal. Under the microscope, it was seen to consist of translucent brown material devoid of any trace of vegetable structure.

Other Occurrences

A vertical coal vein cutting through alluvium and down into phyllite has been recorded by Dr. Ingham (in his unpublished field notes) in a mine on lots 1865 and 2039 at Asam Kumbang near Taiping, 55 miles north of Ipoh.

COMPOSITION OF THE COAL

Seven analyses of coal from vertical veins are given, together with a proximate analysis of the average coal mined from the Tertiary deposits at Batu Arang.

TABLE III

ANALYSES OF COAL OCCURRING AS VERTICAL VEINS IN PERAK, WITH AN ANALYSIS OF THE TERTIARY COAL MINED AT BATU ARANG, SELANGOR

	Moisture	Ash	Volatile Matter	Fixed Carbon	Calorific Value in B.Th.U. per lb.				Colour of Ash
					As Received	Air Dry	Dry	Dry, Ash Free	
	%	%	%	%					
1	27·80	3·22	34·50	34·48	Not Determined				
2	26·22	7·70	42·92	23·16	6,340	6,340	8,590	9,590	
3	25·21	10·24	51·57	15·41	5,950	5,950	7,950	8,850	White
4	20·42	3·22	46·18	23·16	7,050	7,050	8,860	10,170	
5	31·70	6·82	37·75	23·73	5,760	6,060	8,430	9,370	
6	33·20	5·51	36·10	25·19	6,180	6,440	9,250	10,080	
7	27·63	5·89	32·63	33·85	6,400	6,430	8,840	9,630	
8	21·00	7·00	37·00	35·00	9,000	9,400	11,300	13,000	

1. Coal from lot 1934, Allington Hill Estate, near Tapah Road Station, Perak. } Analysis J. C. Shenton, Chemist, Geological Survey Department, F.M.S.

2 to 4. Coal from the Lai Chak Mine, lot 1534, Semoliang, Perak.

5 & 6. Coal from Hin Fatt Mine No. 2, lot 3368, Bidor, Perak.

7. Coal from the Drainage & Irrigation Department Canal at Ulu Ijok, Perak.

8. Proximate analysis of average coal mined at Batu Arang, Selangor.

} Analyses by Messrs. Malayan Collieries, Ltd., Selangor.

CONCLUSIONS CONCERNING THE AGE AND ORIGIN OF THE COAL VEINS

The foregoing detailed description leaves no doubt that the coal found as veins in these thirteen localities in Perak is very much younger than coal mined at Batu Arang, Selangor, known to be Upper Tertiary, and the clearly established very recent age of the coal veins is not the least interesting feature of these unusual occurrences. As suggested by Sir Lewis Fermor, it is probable that the gel material constituting the coal veins originated from wood in the alluvium, and it is described in the accounts of the veins seen in the Hin Fatt Kongsi Mine No. 2 on lot 3368 and in the Heng Bee Kongsi Mine on lot 3329 that wood actually does occur there older than the veins. It is modern wood, well preserved, and there is no reason to think that the alluvium containing it is any older than alluvial beds a few miles away containing Neolithic stone-implements and teeth of *Elephas maximus*, the modern elephant (*Annual Reports of the Geological Survey Department, F.M.S.*, 1936, paragraph 25, 1937, paragraph 29).

Dr. F. S. Sinnatt, Director of the Fuel Research Station of the Department of Scientific and Industrial Research, London, was kind enough to read this paper and to examine specimens of the coal, and analyses made in England under his direction gave results corresponding to those made by the staff of the Malayan Collieries (Table III) if allowance be made for the prolonged air-drying suffered by the samples during transit. Dr. Sinnatt invited attention to the intrusion of sand wedges into coal in the Coal Measures of England (Kendall and Wroot, *Geology of Yorkshire*, 1924, pp. 152–161, and Kendall, *Rept. Bri. Assoc. Adv. of Science*, 192, pp. 69–71), described as results of seismic phenomena. It is unfortunate that the literature is not available in Malaya, and cannot be consulted yet. Our Malayan occurrences illustrate an inverse phenomenon, coal veins intrusive into sand.

The fissures housing these Malayan coal veins are considered to have been formed by small-scale tensional forces which caused the alluvium to open along vertical planes ; in some localities, the bedrock, decomposed schist or phyllite, not appreciably harder than the alluvium, was fractured also. There has been no differential movement between the walls of the fissures other than a simple opening ; there has been no sliding.

Sir Lewis Fermor (*Report upon the Mining Industry of Malaya*, p. 19) has alluded to a "possible uplift of the Main Range consequent upon its lightening due to loss of substance as a result of denudation, *pari passu* with sinking of the coastal plain under the increased load of silt . . .", and it is the opinion of the writer that the fissures occupied by coal veins may have originated from such warping.

The Geomorphology of British Guiana

By S. Bracewell

MR. D. W. BISHOPP'S paper " Some Problems of Geomorphology and Continental Relationship in British Guiana " (*Geol. Mag.*, lxxvii, 1940, p. 305) contains certain erroneous statements of fact and theoretical conclusions founded on them. The following notes deal with the more important of them.

(1) Misinterpretation of the British Admiralty Chart

On page 306 there is a map of the northern part of British Guiana purporting to show the 100, 400, 1,000, and 2,000 metre isobaths. An examination of British Admiralty Chart No. 1801, on which the isobaths are stated to be based, shows that Mr. Bishopp has misread as depths to the ocean floor certain signs which really indicate " no bottom " at the depth given by the figure.

Mr. Bishopp's isobaths indicate a " submarine precipice " crossing the 10th Parallel, a sharp protuberance of the ocean floor with a depth of only 612 metres outside the 2,000 metre line, a projection of the 400 metre line north of the Essequibo River, and a wide " shelf" between the 400 metre and 1,000 metre lines. There is, in fact, no evidence on the British Admiralty chart of the actual existence of these features. The " Dutch Charts of this coast " referred to in the paper are not available to me, but it is unlikely that they differ materially from the British Chart.

(2) Kaieteurian Sandstone between the Essequibo and Courantyne Rivers

In discussing the possibility of a " fault " in the Archean basement coinciding with the present position of the Essequibo River the paper states (p. 320) :—

> " What is much more important is that there is in fact the complete absence, which implies no doubt the removal of the sheet of (Kaieteurian) sandstone from the region between the Corentyne and Essequibo rivers. This would suggest an upward movement and erosion of this block," etc.

But there is ample evidence of the *presence* of Kaieteurian Sandstone in this region. On the 1913 Map of British Guiana the Kaieteurian Formation has been indicated by the late Sir John Harrison at Makari Mountains on the eastern bank of the Essequibo, at Parish's Peak near Itabru Cataract in the

Berbice River, at a point about eight miles below Marlissa Rapids in the Berbice, at Cannister Falls in the Demerara River, and near Wanuto Island and Yurowa River in the Courantyne River. These occurrences have been described in the published reports of Harrison and those of Charles Barrington Brown. The description of the sandstone mountain near Itabru Cataracts, which is given on page 249 of Brown's Report on the Berbice and Demerara Rivers (1873) reads as follows :—

> "On the western side of the Berbice river above Itabru cataract there is a mountain range not far from the river, the upper portion of which is composed of horizontal sandstone beds, resting on quartz-porphyry. They bear a close resemblance to those at Macarri mountain, and are evidently the eastern extension of the same beds. Ascending the mountain side beyond the terraces to a height of 262 feet, I came to the first block of sandstone conglomerate, at first in small numbers, but higher up becoming exceedingly numerous, and lying in confused heaps. At a height of 481 feet the true base of the sandstone formation is reached, and this rock continues to the top. On the surface of the sandstone on the top of the mountain there is some red and brown iron oxide, and amongst it I observed a decomposed iron-stained rock, exceedingly like a decomposed greenstone. On the eastern face of the mountain a great section of sandstone is exposed, of thick beds of sandstone and pebble conglomerate, having a very slight dip to the west with a north and south strike. . . ."

(3) DEPTH OF THE CRYSTALLINE BASEMENT ROCKS NEAR GEORGETOWN

On page 317 it is stated :—

> ". . . the coastal sediments deepen towards the east, the greatest recorded depth being 1,680 feet a little east of Georgetown where the hole is said to have bottomed on crystalline rock."

My interpretation of this statement is that the crystalline rocks were encountered at a depth of 1,680 feet in a hole located a little east of Georgetown. But this is not the case. According to Mr. Noël-Paton (*Geol. Survey Bulletin*, No. 11, p. 26) the greatest recorded depth at which the rock floor has been encountered during drilling operations for artesian water is that of 978 feet at Ogle, some four miles east of Georgetown. According to the same author, at Skeldon on the Courantyne River, which is situated 96 miles south-east of Georgetown, the coastal deposits were penetrated to a depth of 1,627 feet (the greatest recorded depth) and the crystalline rock floor was not reached at that depth.

If my interpretation of Mr. Bishopp's statement is correct it would be of interest to know the locality of the drillhole a little east of Georgetown at which the crystalline rocks were encountered at a depth of 1,680 feet. We have no record of such a drill hole.

The main thesis of Mr. Bishopp's paper appears to be that "the channel of the lower Essequibo marks an ancient break of considerable magnitude". The four main arguments used in this connection are stated on page 319. I am not in agreement with these arguments and I will state my objection to them as briefly as possible.

Argument 1.—Its alignment with the edge of a deep ocean basin on the declivity of a continental platform which closely parallels the present coast line.

As I have indicated above, the edge of the deep ocean basin or submarine precipice shown on Mr. Bishopp's map in alignment with the Essequibo River is non-existent. The data on the Admiralty Chart are, in fact, too meagre to permit the representation of the edge of the ocean basin in sufficient detail for the purpose of this argument.

Argument 2.—Its position as a well-defined dividing line between two geological provinces which differ in several respects.

It is necessary to point out in the first place that differences in topography, geology, and mineralogy between adjacent areas are not in themselves evidence of a "tectonic" break (i.e. a break resulting from deformation of the earth's crust). It is agreed that these differences exist between areas occupied by the "Superficial and Coastal Deposits" on the one hand, and those areas in which the basement rocks outcrop on the other; but the contact between these deposits is a depositional one; the dividing line between the two areas is very irregular and in general does not correspond with the Essequibo River.

It is important to observe that the superficial deposits known as the "White Sand Series" extend in apparently unbroken succession to the west and east of the Essequibo River. To the west they are known to extend to the base of the Pakaraima Mountains in the Potaro and Mazaruni Districts and across the Cuyuni-Barama watershed whilst to the east they extend to the Berbice and Courantyne Rivers (see Fig. No. 2 in *G.S. Bulletin*, No. 11). There is no evidence of any "break" in these deposits at the Essequibo River. Nor is there any evidence of any "break" at this point in the basement on which they rest.

In discussing the possibility of a fault line boundary of the Kaieteurian Formation, on page 320, it is stated:—

> "What is much more important is that there is in fact the complete absence, which implies no doubt the removal, of the sheet of sandstone from the region between the Corentyne and Essequibo rivers. This would suggest an upward movement and erosion of this block . . .", etc., etc.

But as I have indicated above, there is plenty of evidence of the *presence* of this sheet of sandstone between the Essequibo and Corentyne Rivers.

In regard to the mineralogical differences mentioned the most striking are those between the areas of " Superficial and Coastal Deposits " on the one hand and the areas of " Basement Rocks " on the other. In general gold deposits are not found in the former, except in proximity to the basement rocks. Workable gold deposits have been found at a number of localities on the eastern bank of the Essequibo, and on both banks of the Demerara and Berbice Rivers: diamonds have been worked near the Kaieteurian Sandstone in the Berbice River.

On page 318 it is stated that :—

> " The manganiferous phyllite or shear-belt striking east and west at Saxacalli on the lower Essequibo does not apparently cross the river to its eastern bank."

In his report on the occurrence of manganese ore at Saxacalli (*G.S. Bulletin*, No. 6) Mr. Bishopp has stated that " There seems to be little doubt that the ' phyllite ', in a highly decomposed condition is derived from a sheared or mylonitized gneiss. This indeed was indicated by Sir John Harrison in his memorandum : ' The structure at Saxacalli indicates that the manganese ores were derived from manganese-bearing silicates in the gneiss.' " According to Harrison (*Geology of the Goldfields of British Guiana*, pp. 115–116) great masses of a banded felspathic gneiss of massive texture are exposed at Ithaka, a point on the Essequibo River, almost opposite Saxacalli.

It is true that no manganiferous deposits have been found on the right bank of the Essequibo opposite Saxacalli. But the Essequibo River is 2½ miles wide at this point and the revealed strike of the manganese occurrence at Saxacalli is only 1¼ miles. No geological survey has yet been made of the area east of Ithaka. When this is done I have no doubt that it will show an extension of the gneissose rocks for a distance of some miles to the east of the Essequibo River at this point. The apparent absence of manganiferous " phyllite " on the eastern bank of the Essequibo, therefore, is not regarded by the writer as evidence of a tectonic break at this point.

In short, therefore, I do not regard the Essequibo River as a well-defined dividing line between two geological provinces.

Argument 3.—Its position in marking the former locality of a coast line opposite what is now a tectonic depression.

There is evidence of the existence of a former coast line at the foot of the Pakaraima Mountains. Recent work has shown that this coast line was very irregular—there were probably a number of long embayments in the coast line forming the estuaries of rivers flowing from the Pakaraima. But I know of no evidence indicating that the Essequibo River marks the former locality of this coast line.

The evidence in favour of a " tectonic depression " such as that described by Mr. Bishopp in the Berbice area, is inconclusive. It is true that the coastal deposits are thicker at New Amsterdam than at Georgetown, for, whereas at Georgetown the basement rocks were met at a depth of about 700 feet, they were not reached at a depth of 1,474 feet at New Amsterdam or at 1,627 feet at Skeldon on the Courantyne. It has been inferred by Harrison and by Grantham and Noël-Paton that the rock floor may be some 3,000 feet deep on the coastland between the Berbice and Courantyne Rivers. There is, therefore, an *apparent* dip of the basement in a south-easterly direction along a line connecting Georgetown and New Amsterdam ; the gradient of the basement along this line is at least 1 : 300 (i.e. 1,000 feet in 60 miles), and may be as high as 1 : 100, or even slightly higher. It will be observed, however, that this is not a remarkably steep gradient. This gradient is not necessarily the maximum gradient or " true dip " of the basement ; indeed, it appears to the writer more likely that the true dip of the basement is in a *north-easterly* direction, that is, approximately at right angles to the Demerara-Berbice coastline and to the edge of the continental shelf. If the latter view is accepted, it is clear that the greater depth of the basement at New Amsterdam is explainable by the extension of land seawards owing to relatively greater deposition in the Berbice area ; the addition of a strip of land, say 10 miles wide, along the Demerara coast, would have the effect of deepening the basement under this part of the coastline also.

In short, therefore, in my view, this apparent deepening of the coastal deposits in the Berbice area may have been misinterpreted. The elevation of the White Sand Series in the south-west and the depression of the homotaxial coastal deposits in the north-east are due to differential movement about a fulcrum or hinge line which trends north-west across the northern part of the Colony ; there has been uplift of the areas inland and subsidence of the areas seaward of this line. But beyond this there is little or no evidence of folding movement within the superficial deposits of the Colony.

It should be remarked that there is no evidence on the British Admiralty Chart No. 1801 of the " large river channel existing to the north of Berbice " referred to on page 326 of the article.

The late Sir John Harrison was first responsible for this idea. In paragraph 40 of his " Digest of the Results of the Inquiries Concerning the Occurrence of Petroleum and of Pitch in the Colony " (*Sessional Paper* No. 37/1925) he states :—

> " A submerged river-valley north of the estuary of the latter (Courantyne) river is indicated by a sounding of 720 fathoms about 100 miles north of that estuary with soundings of 360 fathoms and of 400 fathoms to its south-east and north-west respectively."

Examination of the Admiralty Chart (with corrections to 1934) shows that the 400 fathom sounding referred to by Harrison is a " no bottom " sounding and that there are soundings of 507 fathoms and 689 fathoms immediately north-west of the 360 fathom one. When due allowance is made for these facts I can find no evidence in the chart of the submerged river-valley referred to.

Argument 4.—Its conformity with certain " fault-line coast " criteria.

These criteria are given on page 325. According to this a " fault-line coast " is normally represented by the interior mature plateau with inland slope, the escarpment, the moderately, or else considerably, dissected coastal zone, the narrow continental shelf, and the steep slope of the ocean deep beyond.

Mr. Bishopp argues that the presence (in his view) of these elements in the block west of the Essequibo and their absence from the block east of the Essequibo is evidence in support of the postulated Essequibo break. He states :—

> " Now it will be noticed that du Toit's criteria apply to the block west of the Essequibo river, but definitely not to the area between the Essequibo and the Corentyne ; they are missing in the region of the Berbice downwarp where rivers run northward to the sea, where there is no high plateau in the interior, and from which region all the Kaieteur formation has disappeared."

As I have pointed out above, the Kaieteur formation has not disappeared from the area between the Essequibo and the Courantyne. It is present in the flat-topped range of mountains which extends across the head of the Demerara River, from Makari Mountain near the Essequibo to Parish's Peak close to the Berbice River, and in the Berbice and Courantyne Rivers. So that, in the first place, Mr. Bishopp's facts are not correct.

In the second place it is somewhat doubtful whether these normal elements of a " fault-line coast " are actually to be found in the area west of the Essequibo.

In the third place, even if the facts were as stated by Mr. Bishopp (and they are not), it is doubtful whether the mere presence or absence of the " criteria " from these comparatively small blocks of the South American coastline can be regarded as evidence of a " tectonic break " similar to that postulated by Mr. Bishopp.

Summarizing the above comments :—

(1) There is no evidence of the alignment of the Essequibo with the edge of a deep ocean basin.

(2) The Essequibo River is not a well-defined dividing line between two geological provinces.

(3) The Essequibo River does not mark the former locality of a coast line ; it is not parallel to a tectonic depression.

(4) The " fault-line coast " criteria described are not restricted to the area west of the Essequibo, and even if they were, this would not necessarily be evidence of a tectonic break along the Essequibo.

There are a number of other controversial statements in the paper. I have attempted to deal only with the chief points raised in the four arguments referred to.

CORRESPONDENCE

GLACIAL DRIFTS

SIR,—I regret that circumstances have not permitted my making an earlier reply to Mr. Carruthers' letter (1941) regarding my note (1940) on Glacial Drifts in Midlothian. The erroneous impression may have been given that I have accepted the reinterpretation which he has put forward.

I should perhaps first answer Mr. Carruthers' accusation of " dismissing " his views. As the purpose of my paper, which I do not suggest necessarily invalidates Mr. Carruthers' conclusions regarding his own district, was to describe and interpret certain local sections of a temporary nature, no detailed consideration of Mr. Carruthers' arguments was called for. Further, I saw no reason to add to the very full discussion at the Geological Society of London. For the same reasons I shall confine myself in this reply to dealing with Mr. Carruthers' opinions only in so far as they affect my paper.

Mr. Carruthers' main point is that the fissures in sands near Roslin filled with boulder clay are post-Glacial frost-wedges. Although he does not make it altogether clear I assume his suggestion is that these wedges are initiated on the surface of the boulder clay, worked downwards through the latter, which is up to 6 feet thick, and then penetrated another 6 feet into the subjacent sands. It is perhaps worth noting at the outset that the examples of frost-wedges described by Mr. Paterson, quoted by Mr. Carruthers, are entirely in sands and gravels. I am aware that frost-wedges in silt and mud occur in Alaska, but I know of no instance of their being recorded in boulder clay, if indeed they could form in a substance of this nature. I am, however, open to correction on this point and shall continue the argument on the assumption that their formation in boulder clay is a possibility. In that case, for every fissure which penetrated into the sands several shallower examples should occur in the boulder clay. None were seen. Further, few deposits reveal weathering more quickly than boulder clay and as the material in the fissures, on Mr. Carruthers' assumption, must have come from the surface it should be less fresh and less cohesive than the unweathered boulder clay resting on the sands. Such is not the case. Lastly, if the fissures in the sands are the continuation of cracks initiated at the surface, the traces of the sides of the fissures should be continued as lines of weakness or of weathering upwards through the boulder clay. No such lines are seen ; unweathered boulder clay crosses the fissures in a completely undisturbed manner.

The proof of the later date of the Upper Boulder Clay does not, however, depend entirely upon the evidence discussed above. There is, among other reasons given in my original paper, the fact that boulder clay lines a large erosion hollow in the sands at Roslin. This feature Mr. Carruthers makes no attempt to explain.

With Mr. Carruthers' second paragraph it is more difficult to deal. It is merely a restatement of faith in his own theory and therefore contains no logical argument against my interpretation of the Roslin drifts. Mr. Carruthers is willing to accept conditions in post-Glacial times sufficiently cold to cause frost-wedges to penetrate 12 feet into boulder clay and sands. Yet, during a temporary withdrawal of the ice, he is unwilling to admit of freezing of sands and gravels strong enough to enable them to resist distortion during a readvance just as readily as a sandstone. In this connection might I draw his attention to my observation of the effects of a severe Scottish winter on the Roslin sands ?

The views Mr. Carruthers has put forward are based mainly on observations made within a fairly limited area. He is quick to impute a lack of scientific outlook to those whom he regards as his opponents. Yet he has no hesitation in dogmatizing about glacial drifts in other parts of the country, an extension of his theory for which there can be no scientific basis without careful examination of local sections, especially as long as the evidence regarding his own area is not so strong as to meet with general acceptance.

J. G. C. ANDERSON.

19 GRANGE TERRACE,
EDINBURGH.
27th October, 1941.

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REVIEW

CRATER LAKE. THE STORY OF ITS ORIGIN. By HOWEL WILLIAMS. pp. xii × 97, with plates and figures in text (not numbered). University of California Press and Cambridge University Press, 1941. Price 10*s*. 6*d*.

This extremely modern book is in a way a reversion to a very early type, since half of it consists of a dialogue during a tour of the lake between intelligent inquirers and an Authority, after the manner of Plato. This is very well done, and manages successfully to escape the patronizing and didactic manner which can be so very unpleasing in writings on this plan.

The first half is a general and extremely clear account of the history of the great volcano, now named Mount Mazama, whose collapse gave rise to the beauties of Crater Lake, Oregon. It may be suggested that avoidance of technicalities has possibly been overdone. After all the book will be read by many geologists, especially amateurs, all of whom may not be expert enough to perceive the reason for the difference in the behaviour of the two kinds of lava described. The word magma is often used and the contrast brought out between the basalts of the fissure eruptions and the andesitic lavas of the explosive volcanoes, but they are all just called lava and no explanation is given of why they behave so differently.

The history of Mount Mazama as here expounded may be described as a mixture of Krakatoa, Montagne Pelée and Katmai, with a touch of Kilauea, the whole being complicated by the Great Ice Age. It is remarkable how ice-striations on the rim of the crater and elsewhere have been utilized in working out the form of the mountain when covered with glaciers before the collapse, which is found to have been of the usual caldera type.

There are some beautiful illustrations, including effective colour plates of the hypothetical appearance of Mazama before and at the time of collapse. The one weak point of the book is the somewhat too " arty " map of the Cascade Range, where it is quite difficult to find Crater Lake.

R. H. R.

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